TRANSPORT OF FINISHED HEIFERS IN WARM AMBIENT TEMPERATURES: AN ASSESSMENT OF TRAILER MICROCLIMATE AND ANIMAL WELL-BEING FOR TWO TRANSPORT DISTANCES

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PERMISSION TO USE STATEMENT

ABSTRACT

The microclimate within naturally-ventilated transport trailers hauling Canadian cattle to slaughter was investigated by recording temperature and relative humidity in one-minute intervals during commercial transport. Conditions on the outside of the trailer (ambient), at the trailer ceiling and at the animal tag-level were monitored. These metrics were used to calculate humidity ratio and temperature humidity index (THI) to further investigate the moisture content of the air and the apparent thermal conditions within the vehicle, respectively. The trailer micro-environment was assessed between trailer compartments and between planes within a given compartment. Five commercial long-haul (940 km) and five commercial short-haul (85 km) warm weather journeys (average daily temperature 24.5°C) were conducted to represent common distances traveled by finished Canadian heifers during summer and early fall. Variations in temperature, THI and humidity ratio were evident within the trailer and the results illustrated the most challenging compartments, in terms of thermal environment, at the front of the trailer and on the top level. Thermal conditions were greater inside the trailer compared to ambient (average 1.97°C for long and short distances combined), greater at the animal-level compared to the trailer ceiling (3.03°C for long and short distances combined) and greater in the center plane compared to the outside walls during long distance journeys. The physiological effect of transport on the cattle was measured through on-going monitoring of vaginal temperature of focal heifers located throughout the trailer. Body temperature recordings showed the ability of the animals under these conditions to dissipate heat acquired through the loading period. Cattle transported long distance however showed a better ability to return to near-baseline body temperature values. Shrink, or body weight loss, was calculated by each compartment of animals for all journeys. Cattle that travelled further lost a greater percentage of body weight ($P < 0.001$) with values of 4.5% and 1.6% for long and short distances, respectively. Further, cattle located in compartments that had higher temperatures and greater moisture levels recorded in the microclimate data showed correspondingly increased body weight loss ($P < 0.05$) suggesting that the nose compartment in particular had a greater potential to induce thermal stress.

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I am ever grateful to the members of my Committee, Drs. Karen Schwartzkopf-Genswein, Trever Crowe and Huiqing Guo, for their ongoing support and guidance. I thank the management and staff of Butte Grain Merchants Ltd. and Lost Lake Feed Yard for their assistance and cooperation in conducting this research.

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List of Abbreviations

AAFC	Agriculture and Agri-Food Canada
ACTH	Adrenocorticotropic Hormone
ATP	Adenosine Triphosphate
CARC	Canadian Agri-Food Research Council
CK	Creatine Kinase
HPA	Hypothalamo-Pituitary-Adrenal
LWSI	Livestock Weather Safety Index
NEFA	Non-esterified Fatty Acid
PCV	Packed Cell Volume
RH	Relative Humidity
RH_{amb}	Ambient, Outside Trailer Relative Humidity
RH_{in}	Inside Trailer Relative Humidity
SCAHAW	Scientific Committee on Animal Health and Welfare
SEM	Standard Error of the Mean
T	Temperature
T_{amb}	Ambient, Outside Trailer Temperature
T_{in}	Inside Trailer Temperature
T_{tag}	Ear Tag Temperature
THI	Temperature Humidity Index
THI_{amb}	Ambient, Outside Temperature Humidity Index
THI_{in}	Inside Trailer Temperature Humidity Index
VFA	Volatile Fatty Acid

W	Humidity Ratio
$\mathbf{W_{amb}}$	Ambient, Outside Humidity Ratio
$\mathbf{W_{in}}$	Inside Trailer Humidity Ratio

1 INTRODUCTION

Transportation is an essential practice for the Canadian beef cattle industry. Most slaughter cattle are fattened at finishing sites located at a distance from processing facilities, necessitating transfer prior to harvest. There is consensus among the scientific community that the transport process (including gathering, loading, transit and unloading) is stressful (Warris, 2004; Swanson and Morrow-Tesch, 2001; Fisher et al., 2009; Knowles, 1999), and as such, it poses a threat to animal welfare. Increased attention has been drawn to the transport of livestock in recent years, driven primarily by societal concern and a need for a better understanding of the effect transportation has on both food quality and food safety (Keeling, 2005; Maraharens et al., 2011). This has resulted in a number of changes to regulations and requirements in Canada and abroad. Most notable is the review of the recommended codes of practice for the care, handling and transport of beef cattle in Canada (CARC, 2011). These changes illustrate the priority that ensuring humane transport takes domestically.

Livestock transport has been an important research topic for many years, particularly in Europe. However, studies on transport of cattle within North America are lacking. Even less common is work involving the transport trailer microclimate in conditions representative of those cattle would experience under typical Canadian conditions and the relationship that the trailer micro-environment has with animal well-being. Thus, this research project was intended to draw attention to this area and to provide some science-based information regarding the relationship between transport conditions and cattle welfare.

2 LITERATURE REVIEW

2.1 CATTLE TRANSPORT IN CANADA

2.1.1 Transport of Finished Cattle

Intensive cattle production sites are typically located away from processing facilities making transport prior to slaughter a necessity. At the beginning of 2011, there were a total of 186 finishing feedlots with a one-time bunk capacity of at least 1000 head in Alberta (Canfax, 2011). This represents a total finishing capacity of 1,565,880 head at any one time for the province. The South Central and Southern regions of the province have the highest density of finishing lots, with 90% of the larger yards located in this area (Canfax, 2011). The placement of these feedlots is such that they are in close proximity to the major beef processing plants in Alberta. However, Canadian cattle have the potential to be transported long distances both domestically and following export of live cattle to the United States for processing. In the year of this study, 682,272 steers and heifers were exported to the United States through ports of entry for slaughter (AAFC, 2011). In a benchmarking study conducted by González et al. (2012a), it was found that 72.9% of all cattle undergoing transport greater than 400 km in length departing from or arriving to Alberta were destined for slaughter. The greatest percentage of long-haul cattle destined for slaughter were transported to Washington (51.46%), followed by Utah (22.47%), Colorado (17.63%) and Nebraska (5.59%).

2.1.2 Climatic Conditions

Livestock transport in Canada can occur under a wide range of environmental conditions presenting unique challenges depending on the time of year. The beef production cycle in Canada results in large numbers of fattened cattle being transported for slaughter during the summer and early fall. González et al. (2012b) reported the highest volumes of slaughter cattle movement between the months of August and November, with equal volumes in these months. However, transport of cattle occurs throughout the year and at multiple stages of the production cycle.

The average daily temperatures reported for the months of July through October for Lethbridge, Alberta between 1971 and 2000 were 18.2°C, 17.7°C, 12.3°C and 7.2°C, respectively (Environment Canada, 2011). The reported daily maximum values were 25.6°C, 25.2°C, 19.3°C and 14.1°C for the four months, respectively (Environment Canada, 2011). Extreme maximum temperatures between 30.0°C and 39.4°C are reported during these months (Environment Canada, 2011). The temperatures in each season pose different challenges to transport and animal welfare, but in particular, the summer months pose a specific threat when animals are at risk of hyperthermia as the temperatures attainable in these months surpass the upper critical temperature of cattle (Randall, 1993). It is important to note that these temperatures represent ambient conditions and that temperatures within a transport trailer may be greater given the stocking density and reduced air flow.

2.1.3 Livestock Transport Trailers

Cattle are typically transported in five-compartment, double-decked, pot-belly aluminum trailers measuring 16.15 m in length. There are a number of different trailer types and axle arrangements within this group of trailer and several types of tractors can be used to pull them. Trailer types are generally based on the number of axles and can be tandem, tri-axle or quad-axle. Trucks are also categorized this way with tandem or tandem with push-axle varieties. Trailer and truck choice depends on a number of factors including the species and size of animals to be transported, and whether transports will be conducted domestically or to the United States. González et al. (2009) reported the most common type of trailer to be the quad-axle, representing 67.8% of trailers used in Alberta.

Transport trailers are made of a high grade aluminum alloy that has been heat treated to make it dent and tear resistant. The roof is an aluminum skin which is riveted to roof bows. Most have an aluminum floor which is welded to a thicker floor plate (Merritt Equipment Co., 2011). The floor is diamond plated to provide a low slip flooring surface. Trailers typically used to transport cattle are composed of five separate compartments on two levels. Three ramps inside the trailer make it possible to access all of the compartments, and aluminum gates separate compartments on the same level. Dimensions of a typical transport trailer (and the one used for data collection) are presented in Figure 2.1. A schematic of the compartment layout within a transport trailer is presented in Figure 2.2. Floor space dimensions and floor space area by compartment are presented in Table 2.1.

The empty weight of most quad-axle transport trailers is between 16,000 and 17,700 kg (González et al., 2009). Canadian regulations dictate a maximum total loaded weight for the trailer as well as maximums for each axle. These requirements are not the same in the United States and typically after crossing the border cattle are moved so that more weight can be placed in the back end of the trailer. The live-weight capacity of transport trailers in Canada is approximately 29 tonnes. On average, a transport trailer will carry 44 finished animals at one time. The allocation of animals inside the truck depends on climatic conditions, animal size and whether the load is being transported only within Canada. Typically, a trailer carrying finished cattle will haul 4 animals in the nose compartment, 13 animals in the deck compartment, 14-15 animals in the belly compartment, 8-9 animals in the back compartment and 4 animals in the doghouse compartment (González et al., 2009).

Air flow within the trailer is achieved via passive ventilation through perforations in the trailer wall. Typically, the front and rear of the trailer are solid except for a space at the top of the rolling door in the back. Additionally, hatches may be located in the roof of the trailer for added ventilation and also to provide an exit for the driver’s safety during loading and unloading. Dimensions of all roof vents are presented in Table 2.2.

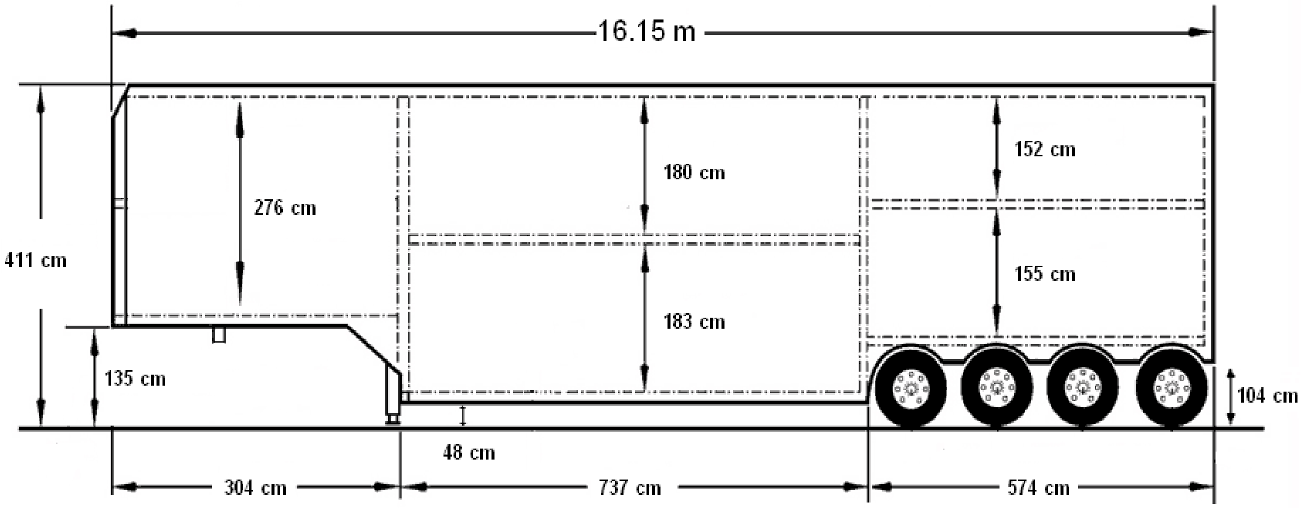


Figure 2.1. Dimensions of the cattle transport trailer used for data collection. Trailer width is 255 cm. Image adapted from Merritt Equipment Co. (http://www.merrittequipment.com/quad-axle/canadian-quad-axle.html).

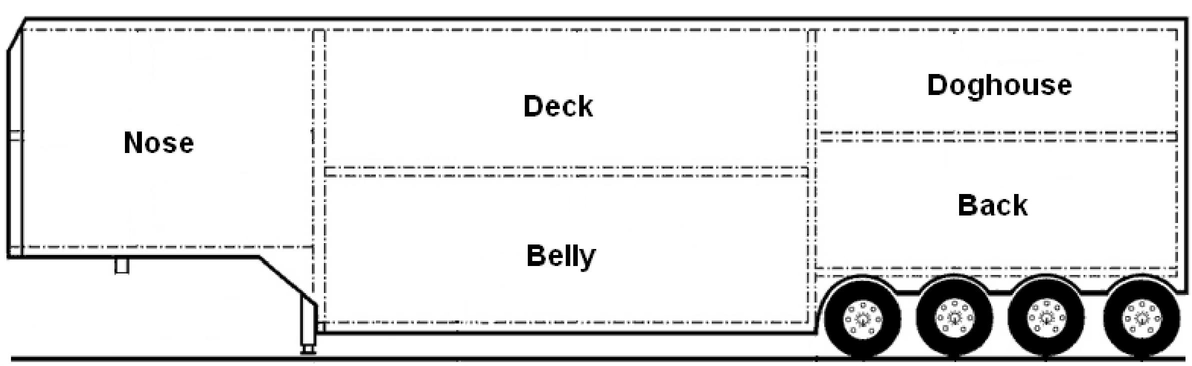


Figure 2.2. Compartment layout in a typical pot belly livestock transport trailer. Image adapted from Merritt Equipment Co. (http://www.merrittequipment.com/quad-axle/canadian-quad-axle.html).

Table 2.1. Floor space dimensions (m) and total area by compartment (m^2) for a quad-axle transport trailer measured in meters.

Compartment	Length (m)	Width (m)	Area (m^2)
Back	5.70	2.55	14.54
Belly	7.29	2.55	18.59
Deck	7.29	2.55	18.59
Doghouse ¾*	5.70 (2.87)	1.41 (1.14)	11.31
Nose	3.04	2.55	7.75

*The doghouse is L-shaped when in the ¾ position and so was divided into two separate areas and presented as two lengths and widths. The two areas were added together to get total area.

Table 2.2. Location and dimension of the three roof vents located in the ceiling of the deck compartment. Position was measured in meters from point (0, 0) at the left front corner (as viewed from the rear) of the deck compartment.

Vent	Position (x, y)	Length (m)	Width (m)
1	(1.75, 0.46)	0.73	0.61
2	(0.22, 3.76)	0.72	0.61
3	(1.76, 6.14)	0.72	0.61

2.2 TRANSPORT AND ANIMAL WELL-BEING

2.2.1 Defining Animal Welfare

The welfare of an individual is described as its state as it attempts to cope with its environment and includes the ease or difficulty experienced in coping (Broom, 2003). Welfare is a broad term which incorporates both the biological functioning of the animal as well as its feelings and mental well-being (Duncan, 2005). As such, an animal's welfare can be described as lying somewhere along a continuum from good to poor. Poor welfare represents failure of the animal to adapt to challenges presented by its environment and can be a result of situations where an animal lacks control over the various interactions it has with its surroundings (Broom, 1991). The transportation event, including the stressors of handling, loading, transit and unloading, can introduce an environment that challenges an animal's ability to cope, and thus poses a threat to animal welfare. Assessing the well-being of transported animals is accomplished using a range of physiological, behavioural, health and carcass quality measurements. In addition, attention should be given to disease, injury or mortality which may result from or be exacerbated by transport (Broom, 2003).

2.2.2 Defining Stress

In the context of animal husbandry, stress is generally conceived as a reflex response or adaptation to a challenge imposed on an animal by its environment. The presence of stress can indicate the animal is experiencing difficulty in coping with the environment and implies a state of reduced or poor welfare. By definition, stress is an environmental effect on an individual which overtaxes its control system for maintaining homeostasis and decreases fitness or appears likely to do so (Broom, 2007). The stress response allows for the allocation of resources based on either direct insults from the environment or how the animal perceives the environment (Siegel and Gross, 2007). When undergoing transportation, an animal is likely experiencing acute stress since the onset of stressors is usually sudden and the responses elicited by the animal occur quickly even though the lasting effects of transport may be chronic. Fisher et al. (2009) placed animal welfare risks during transport into three categories. The categories included: 1) the stress and fear an animal may experience due to handling, loading and the conditions and novelty of transport; 2) welfare risks due to dehydration, energy and fatigue challenges and the relation these have with transport duration; 3) and the risks to the thermal comfort and physical integrity of the animals.

2.2.3 Stressors Associated with Transport

When cattle are transported they undergo a complex series of events including handling, loading, the journey itself and unloading upon reaching their destination. During these events, animals can be subjected to a mixture of adverse stimuli which can subsequently be categorized as being psychological or physical stressors (Grandin, 1997). Psychological stressors result from an animal being unaccustomed to handling and restraint and the fear that can result (Grandin, 1997). In addition, psychological stress can occur as the animal is exposed to new conditions including noise, smell and social restructuring (Nanni Costa, 2009). Feed and water deprivation, extreme climatic conditions and muscle exertion from handling, loading, unloading and maintaining balance in the vehicle are examples of physical stressors an animal may undergo during transportation (Nanni Costa, 2009). Several of these stressors are explored in further detail below.

2.2.3.1 Handling, Loading and Unloading

The initial stage in transportation requires that cattle be removed from their home pen or brought in from pasture and placed in holding pens to allow for sorting, weighing and separating prior to loading. The stress imposed on cattle due to handling is the result of fear (Grandin, 1997) and can be influenced by a number of factors including stockperson training and attitude, cattle temperament, the novelty of the situation, habituation of the animals to handling, whether past experiences were negative (Grandin, 1998), whether animals remain in a group or are isolated (Grignard, 2000) and a variety of animal factors such as age, breed and sex, preconditioning and how recently they have been fed and watered (Schwartzkopf-Genswein et al., 2007).

Loading of cattle onto the transport trailer is considered by many to be the most stressful stage of transport. This may be due to the requirement of physical exertion, the novelty of the trailer environment, the noise generated when stepping into the trailer, confinement, or because of contact with people. Contact with stockpersons can be especially stressful when the stockperson is undertrained or does not value the animals' well-being (Broom, 2007).

Several studies have quantified the stress imposed on cattle during loading. Increases in serum cortisol concentrations following loading have been reported (Kent and Ewbank, 1983; Kenny and Tarrant, 1987). Similarly, Francesco et al. (1990) found elevated serum cortisol and non-esterified fatty acid (NEFA) concentrations following loading onto a stationary transport simulator which were similar to concentrations found during transport. Maximal values were reached between 15 and 30 minutes after loading and gradually returned to baseline values suggesting that the initial loading event was the most stressful. Tennessen and others (1984) found that the only large increase in heart rate for bulls and steers being transported occurred at the time of loading. The increase in heart rate was followed by a subsequent gradual decline in heart rate, suggesting the loading event was more stressful than transport itself. The researchers suggested that this may be a result of the novel trailer environment. More recently, Maria et al. (2004) developed an objective scoring system for evaluating the stress imposed on cattle during loading and unloading. They used a variety of behavioural measures such as falling, turning, balking and vocalization in addition to the time taken to load or unload and compared them to some physiological parameters of stress. It was found that loading was more stressful than unloading and had a greater potential to decrease welfare. In a similar study, Minka and Ayo (2007), using the same scoring system, found that loading increased the number of behavioural activities including slipping, falling and mounting with a corresponding increase in injuries such as tissue wounds and fractures. Increased loading time was found to result in an increased number of contusions and lacerations to the thoracic and abdominal walls (Minka and Ayo, 2007).

2.2.3.2 Feed and Water Withdrawal

It is recommended that cattle be fasted for 12 to 24 hours prior to slaughter (Savell and Smith, 2004). Feed and water are generally withdrawn prior to travel in order to decrease the digesta load in the gastrointestinal tract to minimize soiling of other animals onboard and the vehicle itself, and to decrease the risk of carcass contamination at the time of slaughter (Hogan et al., 2007). In Canada, the current regulations allow for cattle to be transported for up to 52 hours without provision of food or water (CARC, 2011). This means that animals may be subjected to extended periods of fasting which may induce stress due to the deprivation of nutrients on its own or due to the complex interaction it can create with other stressors.

An interruption in nutrient supply, such as that experienced during feed and water withdrawal and subsequent transport, can have many effects on the animal including changes to the functioning of the rumen and digestive tract, challenges to tissue homeostasis, alterations in disease resistance and rumen microbial ecology, decreased meat quality and increased body weight loss (Hogan et al., 2007). The welfare of the animal is affected through feelings of hunger and thirst (Earley et al., 2006) and the possible frustration that can occur from being prevented from satisfying these drives.

Fasting can result in a number of changes to the rumen environment and to general metabolism in the animal. Energy depletion results in increased plasma NEFA and a decrease in plasma glucose as it is used as an energy source (Alam et al., 2010; Galyean et al., 1981). Additionally, ruminal pH tends to increase (Galyean et al., 1981) and fasting-induced fat mobilization occurs (Gregory, 2008). Fasting in combination with transport resulted in higher volatile fatty acid (VFA) concentrations in a study by Galyean and others (1981). These findings are likely the result of changes in rumen motility and passage rates coupled with low rumen volume, poor absorption and differential absorption of VFAs and water (Galyean et al., 1981).

Dehydration can occur when water deprivation exceeds normal physiological limits and results in loss of water from intra and extracellular fluids (Alam et al., 2010). The ability of the animal to regulate homeostasis is challenged in periods of dehydration because the movement of ions across membranes depends on their relative concentrations in the intra and extracellular fluids (Hogan et al., 2007). The concentrations of ions are directly related to the water content of the body and as such, any changes to body water content can result in the inability to maintain body pH, osmotic pressure and acid-base balance (Hogan et al., 2007). Alam et al. (2010) described the condition of animals following long-distance transport as it related to dehydration.

The study found increased packed cell volume (PCV) in the blood, increased plasma osmolality, increased plasma sodium and protein concentrations and increased urine specificity. All of these changes can be linked to the onset of drinking and have been used to describe the feeling of thirst.

2.2.3.3 Motion, Noise and Vibrations

The animal is subjected to a number of non-climatic stressors inside the transport vehicle during transit. These include, but are not limited to, noise, vibration and vehicle motion (Francesco et al., 1990; Randall, 1992). Physical strain is placed on the animal in trying to maintain balance and in the event of a fall (Kenny and Tarrant, 1987). Psychologically, the animal may be stressed in terms of fear or because of the novelty of the situation (Grandin, 1997).

Waynert et al. (1998) described how shouting and the banging of gates can cause a fear reaction in cattle. Such noises are likely to be experienced by cattle during handling prior to loading and at unloading. The suddenness, novelty and unexpected nature of sounds are suggested to elicit a fearful response especially when the sound is novel. Sounds can also be associated with a previous negative experience. It was found that heart rate and movement increased in heifers exposed to noise, with a greater response to shouting (Waynert et al., 1998).

Francesco et al. (1990) studied the response of cattle to handling and the noises during transport. It was found that the animals had elevated serum cortisol and NEFA concentrations and that the responses were the same when loading or noise alone were studied, signifying that there is no additive effect.

On a livestock transporter, the interfaces between the animals and the vehicle are not designed to reduce vibration or provide shock absorption (Randall, 1992). The type of road can influence the vibrations cattle experience and the response of animals to transport. For example, Eldridge et al. (1988) found heart rates of cattle to be lower when transported over smooth highways compared to rough country roads or suburban roads with a number of turns and intersections.

Maintenance of balance is likely the most physically strenuous part of transport once the animal has been loaded. Serious injury or suffocation can occur if the animal is not able to remain upright. Observations show cattle have regular minor losses of balance during transit and quickly shift their footing to regain balance. Kenny and Tarrant (1987) described 95% of losses of balance as being the result of driving practices such as braking, gear changes and cornering. The same study found an increase in the physiological response and a decrease in social behaviours as the complexity of the transport treatment increased from loading and unloading to confinement on a stationary vehicle to confinement on a moving vehicle. The authors concluded that the motion of the vehicle may be the most stressful part of the transport event.

Muscle exertion and fatigue due to transportation have been studied extensively using circulating levels of the enzyme creatine kinase (CK). Creatine kinase is required in the muscle to make ATP available as an energy substrate in muscle contraction. During exercise or tissue damage, CK levels in the blood increase as it leaks from cells (Knowles and Warriss, 2007). Therefore, elevated CK levels following transport are indicative of muscle activity. Such findings have been reported by Tadich et al. (2005) and Buckham and Sporer et al. (2008).

2.3 ANIMAL RESPONSES AND OUTCOMES OF TRANSPORT STRESS

Various physiological, behavioural and immunological observations have been made to assess cattle responses to transportation. Stress and animal welfare may be evaluated using a variety of parameters. Many authors have observed increases in plasma constituents such as cortisol (Buckham Sporer et al., 2007; Behrends et al., 2009; Buckham Sporer et al., 2008; Gupta et al., 2007; Fazio et al., 2005; Kenny and Tarrant, 1992; Odore et al., 2004; Warriss et al., 1995; Crookshank et al., 1979; Fell and Shutt, 1986) and adrenocorticotropic hormone (ACTH) (Dixit et al., 2001) which signal the activation of the HPA-axis in cattle in response to the stress of transport. Other measures such as increased total leukocytes (Blecha et al., 1984; Buckham Sporer et al., 2008) and increased neutrophil counts (Blecha et al., 1984; Gupta et al., 2007) suggest an immunological response to transport. Further, muscle exertion from handling and maintaining balance within the vehicle and the overall effect of fatigue are reflected in increased CK levels (Knowles and Warriss, 2007; Tadich et al., 2005; Buckham Sporer et al., 2008).

Heart rate is a valuable measure of stress and has also been found to increase during transport (Uetake et al., 2009; Dixit et al., 2001; Knowles, 1999; Tarrant, 1990). The physical well-being of the animal has been assessed using measures such as bruising (Tarrant, 1990; Van Donkersgoed et al., 2001), injuries and mortality (Warren et al., 2010; Malena et al., 2006). Although the behaviour of animals during transport is difficult to measure it is valuable in understanding the welfare of animals onboard. Several authors have attempted to study behaviour both when animals are loaded and during lairage and observed restlessness, lying and orientation to travel (Tarrant, 1990; Knowles 1999; Tarrant and Grandin, 2000; Eicher, 2001).

The previous section on stressors encountered during transport addressed the effect of several stressful events or situations during transport individually. The following section looks at several general responses to transport stress investigated in this work and presents each in detail.

2.3.1 Body Temperature

An animal's body temperature can be a useful tool when assessing its relationship with its environment. Increases in the body temperature of a homeothermic animal can indicate a disruption in homeostasis regardless of whether these changes were brought about by physical or psychological challenges. Body temperature can be an indicator of stress (Yousef, 1983). During times of stress, a general physiologic response is prompted in the body. This stress response is mediated by the release of ACTH and the subsequent increased release of cortisol from the adrenal gland (Simensen et al., 1980). Stress-induced increases in cortisol brought about by psychological factors can result in the animal experiencing increases in body temperature and entering a state of stress hyperthermia (Parrott et al., 1999). If the elevated body temperature is sustained in an otherwise healthy animal, this may represent a state of distress and, therefore, be indicative of reduced welfare (Parrott et al., 1999).

Body temperature is also a reliable indicator of thermal balance. It is a sensitive marker of the physiological response to heat stress because, under normal conditions, body temperature is nearly constant (Silanikove, 2000). An animal must maintain equilibrium with its environment in order for body temperature to remain constant. Heat stress occurs under conditions where animals experience difficulty in dissipating heat. Under such conditions and at temperatures above the upper critical temperature of an individual, core body temperatures will increase (Lefcourt and Adams, 1996; Schrama et al., 1996) because heat is not as easily dissipated and therefore reflects total body heat content (Curtis, 1983) and as such is an excellent indicator of an animal's susceptibility to heat load (Mader et al., 2006).

2.3.2 Shrink

The transportation of cattle is associated with the loss of live weight (or shrink) and the effect this has on overall carcass yield. There are two types of shrink. Fill shrink is the result of feed and water deprivation and the resulting loss of rumen contents, manure, urine and respiratory exchange. Carcass shrink is the loss of extra and intracellular fluids through sweating, respiration and oxidation and may account for more than half of the total body weight loss (Barnes et al., 1990; Self and Gay, 1972; Jones et al. 1990). It is estimated that the rate of loss due to food and water deprivation alone is around 0.75% per day for steers but when deprivation is combined with transport, weight is lost more rapidly (Shorthose, 1965). This is due to the adrenocorticoid stress response elicited when cattle undergo transport (Parker et al. 2003). The stress response results in the release of cortisol which can further increase fecal and urinary excretion as well as the mobilization of energy reserves above those of a non-transported, fasted animal (Fell and Shutt, 1986; Phillips et al., 1982). Although shrink is a normal physiological process all animals will undergo during transport, the rate at which weight is lost can be influenced by a number of variables related to the transport process including distance, or duration of travel, driver skill and road conditions, and climatic conditions.

Shrink during transportation has both economic and animal welfare implications and thus minimizing weight loss is of value. In terms of economics, not only is the value of the animal decreased because of losses in carcass yield due to the immobilization of body tissues to maintain the vital processes of the body and the dehydration that occurs, value may also be lost in the weight of edible offal such as the liver (Warris, 1990). From an animal welfare perspective, increased weight loss could be the result of extended periods of feed and water withdrawal or an outcome of a stressful situation.

2.4 HEAT LOAD, THERMAL STRESS AND SUMMER TRANSPORT

The relocation of animals during summer months poses a particular challenge to the livestock industry. Warm or hot temperatures have a greater effect on animals than cold temperatures as animals cannot survive for long periods when temperatures exceed 5ºC higher than normal body temperature (the average body temperature for beef cattle is 38.6ºC (The Merck Veterinary Manual, 2008)) but can withstand temperatures 20 to 60ºC lower than body temperature (Curtis, 1983). Animal well-being can be compromised when the thresholds for coping and compensatory mechanisms are exceeded by adverse environmental stressors such as acute heat loads (Hahn, 1999). Feedlot cattle near market weight are of special concern because they are vulnerable to hot weather (Hahn, 1999). High temperatures in combination with high humidity are of interest, because the resulting heat stress can cause fatalities in beef animals (Hahn, 1999; Mader et al., 2006).

2.4.1 Thermoregulation in Cattle

Environmental management in beef cattle is important because the conditions to which they are exposed directly affect their ability to maintain homeostasis and thus their well-being. Cattle are homeotherms, meaning that they can keep their core body temperature relatively constant despite fluctuations in environmental temperatures. This ability is essential to vital and productive processes. Homeothermy depends on the balance of metabolic heat production, heat gain from the environment, heat loss to the environment and the change in body temperature over time (Curtis, 1983).

There are four main ways in which cattle exchange heat with their environment: conduction, convection, radiation and evaporation (Curtis, 1983). An animal may gain heat during transport via conduction through contact with the trailer floor, trailer walls and with other animals. Heat may also be transferred to the animal as heat is radiated from the trailer ceiling and walls. During summer transport, heat must be dissipated to the environment to avoid a positive heat balance. In terms of heat loss to the environment during transportation in hot weather, convection and evaporation are the main avenues. In the process of convection, heat from the core is moved to the body surface where it is dissipated to the air through sensible exchange following a thermal gradient (Curtis, 1983). Heat is more readily lost to the environment when there is a more pronounced temperature gradient between the animal and the surrounding air. As such, when ambient temperatures increase, sensible heat loss becomes less effective. Heat may also be dispersed to the environment through evaporation of water from the skin surface and respiratory tract. In this process, heat moves latently through water droplets following a vapour pressure gradient from the animal surface to the surrounding air (Curtis, 1983). This process depends greatly on the water content of the air. When the water content of the air is high, evaporative heat loss becomes less effective.

2.4.2 Heat Stress

Heat stress occurs when an animal is not able to effectively dissipate heat to the environment resulting in a positive heat balance and thus a heat load. This state is detrimental to homeotherms whose core body temperature must be maintained within narrow limits. West

(2003) describes the conditions in which heat stress is likely. The non-evaporative means of cooling for cattle (radiation, convection and conduction) become less effective as the temperature of the immediate environment increases and the thermal gradient is decreased. This situation results in the animal relying on evaporative means of cooling through panting and sweating. In times of high humidity levels, the moisture content of the air is higher and thus the vapour pressure gradient necessary for latent heat exchange is decreased. Evaporative cooling is thus compromised because moisture exchange with the air is reduced. Therefore, high temperatures coupled with high humidity levels restrict the animal's ability to dissipate enough heat to prevent a rise in body temperature.

Heat stress in feedlot cattle is well documented (Morrison, 1983; Mader, 2003; Mader et al., 2006, 2007 and 2010; Scharf et al., 2011; Silanikove, 2000; Turnpenny et al., 2000a and 2000b). The basic mechanisms of how the animal reacts to changes in the thermal environment are the same whether that animal is located in the feedlot or on the transport trailer. However, the added stress of the transport environment may alter the animal's ability to cope.

2.4.3 Temperature Humidity Index

Due to the combined effects of the thermal and vapour pressure properties of the environment on the animal, a temperature humidity index (THI; Thom, 1959) was developed. The THI has been widely used as an indicator of thermal stress in cattle (Gaughan et al., 2008; Hahn, 1999). THI also forms the basis of the Livestock Weather Safety Index (LWSI; LCI, 1970) which is used as a benchmark for assigning heat stress levels to different categories. The LWSI classifies normal THI levels as being less than 74. The alert level lies between THI of 74 and 78.9. A dangerous THI is classified as 79 to 83.9 and emergency levels exist at a THI of 84 or above (Mader et al., 2006). There are limitations to the THI because it does not account for windspeed and the positive effect it can have on convective cooling or the effect of solar radiation on the heat accumulated by an animal (Mader et al., 2006; St-Pierre et al., 2003; Brown-Brandl et al., 2005). Further, THI does not account for the cumulative effects of heat loads acquired the previous day, the influence of natural cooling during the night or the amount of time an animal is exposed to a THI level above that to which it is acclimated and thus may under or overestimate the effect of an environment (Gaughan et al., 2008). However, the index is still useful as a 1-dimensional description of the thermal situation or intensity at one point in time, especially in an environment such as that inside a transport trailer where measurement of variables such as air speed is difficult.

2.4.4 Trailer Microclimate

Although there are many stressors during transport that may affect animal welfare, it has been documented that it is the internal microenvironment of the transport vehicle that poses the greatest threat to animal well-being (McGlone et al., 1993; Knowles, 1998; Hall and Bradshaw, 1998). The microclimate is composed of a number of factors involved in the heat exchange process which occurs between an animal and its environment. These factors include air temperature and moisture content, thermal radiation and air flow, and determine whether an animal experiences climatic stress (Hahn et al., 2003; Schrama et al., 1996). Air temperature often plays the primary role in driving heat exchange, however, the other factors must be considered to provide an adequate expression of their modifying influence on an organism (Hahn et al., 2003).

Animals in transit lose a large amount of heat and water inside the vehicle. Under warm conditions, the water loss of the animal due to panting or sweating may exaggerate hot, humid conditions at the animal level (Kettlewell et al., 2000). Haley (2008) has suggested that internal trailer microclimate is more strongly associated with the in-transit losses of pigs than the external temperature and humidity. It is proposed that the ideal thermal micro-environment within transport vehicles should allow for optimal sensible and latent heat exchange to maintain homeothermy (Kettlewell et al., 2001).

Randall (1993) conducted a study to identify the environmental parameters necessary to define comfort for livestock on transporters. He concluded that appropriate temperatures are dependent on a number of factors including species, age, air speed, floor thermal properties, the number of animals loaded and the animal's level of acclimatization. Ultimately, he concluded that an ambient temperature of 30ºC should not be exceeded for cattle, and that transport should be avoided near this temperature if humidity levels are also high. This conclusion is supported by the findings of Gonzalez et al. (2012) who found the likelihood of an animal becoming non-ambulatory during transport to increase when ambient temperature at the midpoint of the journey exceeded 30ºC. The European Commission has established standards for the microclimate inside animal transport road vehicles based on the results of a study on temperature during animal transport performed by their Scientific Committee on Animal Health and Animal Welfare (SCAHAW, 1999). The Commission established temperature requirements based on the thermal comfort zones of the animal as well as lower and upper critical temperature levels. The main criterion they developed is to remain below the upper critical temperature to which the animal is acclimatized and that temperatures up to 30ºC are generally acceptable in accordance to Randall's findings. The report also recognizes the role of humidity on the perceived temperature and suggests changes to the upper critical temperature as humidity rises. For example, calves have an upper critical temperature of 30ºC if the humidity is less than 60%. If humidity is greater than 80%, the upper critical temperature is adjusted to 27ºC. The report makes several final recommendations including that all transport vehicles be equipped with a monitoring system to observe trailer microclimate conditions (SCAHAW, 1999).

Air flow within the trailer is important for altering the microclimate by removing heat and moisture and aiding in convective cooling. There are two main effects of an appropriate ventilation system: to provide a temperature gradient between the animal and its surroundings to facilitate heat exchange, and to remove moisture from the immediate environment around an animal to create an improved water vapour density gradient which favours evaporative heat loss (Kettlewell et al., 2001). In Europe, transport vehicles are often outfitted with mechanical ventilation systems. This is not the case for North America where ventilation of transport trailers occurs by natural air flow. This means that animals in North America may experience different microclimates than those in mechanically ventilated vehicles. For example, vehicles relying on air movement for ventilation may experience thermal stress conditions when the vehicle is stationary. Such conditions were documented by Fisher et al. (2004) in a study on sheep which found THI increases during stationary periods at most ambient summer temperatures and can be detrimental to animal welfare. Studies such as this illustrate a need for research focused on transport vehicles typical to those used in Canadian systems. Although the European Commission's report on microclimate is useful as a guideline, it does not represent North American practices.

2.5 TRANSPORTATION DISTANCE

2.5.1 Special Concerns of Transport Distance

An animal's response to stressors depends on the duration and intensity of the stressors (Malena et al., 2006). Therefore, total transit duration may affect animal welfare. The limited number of slaughter facilities within Canada and the size of the country mean that cattle may be transported for long durations. In fact, a recent study on transport of Canadian cattle found the average long distance trip (greater than 750 km) lasts 16 hours and covers 1080 km (Schwartzkopf-Genswein et al., 2009). This distance could be significantly higher since current regulations in Canada allow cattle to be transported for 48 hours unless they can reach their final destination within 52 hours (CARC, 2001).

Research on the influence of transport distance on cattle well-being is limited and generally focuses on behavioural observations and circulating hormone levels as indicators of stress. For example, in a review by Knowles (1999) on the road transport of cattle, physiological responses to transit stress included an increase in circulating levels of glucose, cortisol and free fatty acids which indicated the activation of the HPA axis. As well, increased levels of muscle enzymes, such as creatine kinase, indicated muscle exertion, and increased white blood cell and neutrophil counts demonstrated an effect on the immune system. These findings are supported by Tadich et al. (2000), Marahrens et al. (2003), Crookshank et al. (1979), Simensen et al. (1980), Kent and Ewbank (1983), Warriss et al. (1995), Grandin (1997) and Mitchell et al. (1988). However, these studies state the effects of transport in general and often do not make direct comparisons between long and short transport distances. A study by Nanni Costa et al. (2003) conducted in Northern Italy directly compared the effects of long versus short transit on cattle. They did not find significant evidence to suggest that either transit time or environmental condition affected blood plasma constituents or meat quality parameters and ultimately concluded that neither long nor short journey times were particularly stressful to the animals. However, this study classified short distance transport as 100 km and long distance transport as 300 km because 50% of cattle were from farms located no more than 100 km from the slaughter facility and only 9% of cattle traveled further than 300 km to the abattoir. These distances are not representative of practices in North America which outlines why studies assessing transport distances over 300 km are required.

It is postulated that the length of transport has an effect on weight loss, with the greatest loss occurring in the first few hours of transport (Barnes et al., 1990) with actual tissue shrink accounting for around 53% of body weight loss (Self and Gay, 1972). Knowles et al. (1999) observed no effect of journey time of body weight loss when mature steers and heifers (average weight of 571.5 kg) were transported for 14, 21, 26 or 31 hours. However, a greater rate of weight loss occurred in the early stages of transport most likely due to loss of gut fill. The weight loss from urine and feces can account for 40 to 50% of total weight loss in feeder calves (Phillips, 1991). The study transporting animals up to 31 hours may not be a reliable indicator of true weight loss because all animals received a rest stop after 14 hours where water was provided. Warris et al. (1995) transported 12- to 18-month old steers 286, 536 or 738 km. Shrink was found to increase with transport distance with values of 4.6, 6.5 and 7%, respectively. Similarly, a study by Gallo et al. (2000) found shrink to increase with transport duration as shown in their results of 4.6, 7.3, 8.9 and 11.9% for 3, 6, 12 and 24 hours of summer transport, respectively.

With respect to meat quality and transport distance, Jones and Tong (1989) found that the incidence of dark cutting beef increased from 0.78% to 0.98% as transport distance increased from less than 100 to greater than 300 km. Gallo et al. (2000) found that long and short journeys can both produce increases in meat pH depending on the conditions of each journey.

Behaviour during transport and lairage has also been assessed as a measure of stress in transported cattle. Jarvis et al. (1996) found cattle traveling longer distances spent more time lying down and drinking during lairage than cattle transported shorter distances. A study by Tarrant (1990) found that steers did not lie down on the truck when journeys were 1 to 4 hours in length but would occasionally lay down on longer journeys of 24 hours. Both studies concluded that transit length affects animal behaviour and that animals transported longer distances show more signs of fatigue.

Mortality rates in cattle during transport have also been studied because of the economics of death loss. In studies by Malena et al. (2006) the incidence of mortality in fattened cattle during transport was assessed. These studies found the transport-related mortality rate to be $0.007 \pm 0.003\%$. This finding is relatively low, indicating that fattened cattle are fairly resistant to transport stress as compared to dairy cattle and calves which present mortality rates of 0.0396% and 0.0269%, respectively. It was also observed that increases in travel distance resulted in increased mortality rates from $0.004 \pm 0.002\%$ at a distance of 50 km to $0.024 \pm 0.027\%$ at distances over 300 km (Malena et al., 2006). These results indicate that transport-related mortality rates increased as transit distance increased as a result of the stress load on the animals.

2.6 CONCLUSIONS

Transportation is a necessity for slaughter cattle in Canada. It is important to understand the process and the potential areas for poor welfare since evidence exists to suggest transportation has the potential to cause stress and thus threaten animal well-being.

Warm temperatures may hinder an animal's ability to dissipate heat, especially in combination with high humidity levels. This raises concern for heat stress in animals transported during North American summer conditions.

Little is known about the conditions cattle are exposed to inside commercial cattle trailers traveling in North America and the connection between trailer microclimate and animal welfare.

2.7 STUDY OBJECTIVES

The objectives of this study were to investigate the effects of short and long transport distances on the environment within a commercial Canadian cattle transport trailer and the possible risks this environment may pose to the well-being of market-weight heifers transported during summer conditions. The animal's ability to cope with its environment was investigated by observing the weight lost during transport and changes in body temperature.

3 TRANSPORT OF FINISHED HEIFERS IN WARM AMBIENT TEMPERATURES: AN ASSESSMENT OF TRAILER MICROCLIMATE AND ANIMAL WELL-BEING FOR TWO TRANSPORT DISTANCES

3.1 INTRODUCTION

Commercial feedlot production in North America relies on the ability to accumulate large numbers of cattle for feeding and then transporting like-groups of cattle to commercial slaughter facilities for processing. All cattle arriving at a slaughter facility have been transported at least once in their lifetime, more likely three or more times. Transportation is often considered a stressful event and has the potential to cause both physical and psychological stressors on the animals (Grandin, 1997). Cattle may encounter physical or psychological challenges during the handling, loading and unloading events (Kent and Ewbank, 1983; Kenny and Tarrant, 1987; Maria et al., 2004; Minka and Ayo, 2007), by experiencing varying levels of feed and water withdrawal (Hogan et al., 2007; Earley et al., 2006; Alam et al., 2010) and through the motion, noise and vibrations experienced while on-board a vehicle in transit (Francesco et al., 1990; Eldridge et al., 1988). Further, the apparent thermal micro-environment within a transport trailer has the potential to be one of the most significant stressors to which livestock are exposed (Kettlewell et al., 2001). The temperature experienced inside a cattle liner is a function of a number of factors including the outside or ambient temperature, heat and moisture production inside the trailer and the ventilating air flow through the vehicle (Kettlewell et al., 2001).

Little is known about the conditions animals experience when transported in naturally ventilated trailers under North American warm weather conditions. Further, although there is evidence that stress may result in changes in body temperature (Yousef, 1983; Parrott et al.,

1999) and increased levels of body weight loss (or shrink) (González et al., 2012b), the relationships between transport trailer microclimate and animal well-being have not been described. Therefore, the objective of this study was to assess the trailer microclimate during, and the responses of cattle to, two distances of commercial transport conducted under warm weather conditions.

3.2 MATERIALS AND METHODS

3.2.1 Animals, Experimental Design and Transport Trailer

This study was conducted with the cooperation of a commercial feedlot near Enchant, Alberta (50º 09’10 72”N; 112º 21’ 47 53”W, Elevation 793 m) between June and October of 2008. A total of 455 mixed-breed commercial heifers destined for slaughter with an average market weight of 621.9 ± 43.8 kg were used in the study. Each load of heifers was housed together prior to the study and were fed a standard finishing ration.

Depending on the time that the heifers reached market weight, they were assigned to either a long (940 km) or a short transport distance (85 km) to slaughter. These distances were selected based on the proximity of the feedlot to two processing facilities and represent common distances traveled by cattle departing from the Lethbridge, Alberta area. A total of 10 independent trips were assessed; five replicates at each journey length. Each long-haul journey was conducted on different days whereas three short-hauls were conducted one after another on one day and two one after another on a second day. Each trip was carried out by the same driver with extensive experience in cattle hauling (over 10 years) who had completed a driver training course for livestock transport. This driver was selected for the study to ensure low-stress handling of the cattle and expert driving techniques. The same trailer (2008 Cattle Drive Quad Axle, Merritt Equipment Co., Henderson, CO, USA 80640, pulled by a 2004 Western Star 4900EX) was also used for every trip. The roof hatches of the trailer were left open for all journeys and the doghouse remained in the ¾ position. Bedding was not supplied in the trailer as per current operating standards of the trucking company, which is also representative of the majority of commercial practices in western Canada. Heifers were loaded following industry practices for loading density. The back, belly and deck compartments had similar loading densities between 420 and 470 kg/m^2, while the nose had a loading density slightly lower at 400 kg/m^2, and the doghouse much lower at 210 and 275 kg/m^2 (before and after the Canada/US border, respectively).

Approximately one week prior to shipping, the feedlot weighed and sorted animals to assemble loads of cattle to be sent to slaughter. At this time, individual animal weights were collected and auction tags were applied to the animals' backs to aid in individual identification of study animals on the processing line. Additionally, 11 focal heifers for each load were selected by randomly choosing animals from the main load. Focal heifers were sorted from the main group and housed separately until shipping. Focal heifers were handled a second time approximately two days prior to transport to fit them with devices to monitor core body temperature and animal-level microclimate data collection.

On the day of transport, the focal heifers were mixed with the non-focal heifers in the study load such that the number of focal animals was always constant between loads. Similarly, loading density and number of head per compartment were arranged to be as similar as possible between loads and within the range of acceptable industry standards. The number of animals per compartment and number of focal animals per compartment are shown in Tables 3.1 to 3.3.

Following loading, heifers were transported for approximately 940 km or 12 hours to Pasco, Washington (46º 14’ 22” North, 119º 6’ 2” West, Elevation 119.8 m) for long-haul journeys or for approximately 85 km or one hour to Brooks, Alberta (50^{o} 34’ 1” North, 111^{o} 53’ 41”West, Elevation 759.9 m) for short-haul journeys. For each treatment, the final destination for the animals was a slaughter plant. Cattle traveling to Brooks were unloaded and slaughtered within two hours of their arrival at the processing plant whereas, cattle traveling to Pasco were unloaded into lairage pens where they had access to water while they awaited slaughter the following morning.

Table 3.1. Loading scheme for long-haul trips in number of animals per compartment before and after the Canadian border.

Trip	Total	Nose	Deck (Canada)	Doghouse (Canada)	Belly	Back	Deck (U.S.)	Doghouse (U.S.)
1	46	5	14	4	13	10	13	5
2	46	5	14	4	13	10	12	6
3	46	5	14	4	13	10	11	7
4	46	5	14	4	13	10	11	7
5	46	5	14	4	13	10	11	7

Table 3.2. Loading scheme for short-haul trips in number of animals per compartment.

Trip	Total	Nose	Deck	Doghouse	Belly	Back
1	45	5	13	4	13	10
2	45	5	13	4	13	10
3	45	5	13	4	13	10
4	45	5	13	4	13	10
5	45	5	13	4	13	10

Table 3.3. Number of focal animals by trailer compartment.

	Total	Nose	Deck	Doghouse	Belly	Back
Short-Haul	11	1	3	1	3	3
Long-Haul	11	1	3	1	3	3

3.2.2 Data Collection

3.2.2.1 Trailer Microclimate

Temperature and relative humidity were monitored in each of the five trailer compartments. A total of 43 sensors (Hygrochron Temperature/Humidity Logger, iButton DS1923, Maxim Integrated Products, Inc., Sunnyvale, CA, USA 94086; accuracy of ±0.5°C) set to record data at one-minute intervals for the duration of each journey were attached to a 0.02 x 0.02 m piece of wood fastened to the I-beams of the trailer such that contact could not be made with either the roof of the trailer or the animals inside. The sensors were positioned in three parallel vertical planes; one corresponding to the midline of the trailer and one on either side. Sensors in the centre plane were 126.5 cm from either outside wall. Sensors located along the sides of the liner were 15.2 cm from the outside wall. A detailed description of each individual sensor's location is shown in Table 3.4. Each compartment contained a number of sensors such that the sensor to compartment area ratio was similar. This resulted in the nose having five sensors, the belly and deck having 11 and the back and doghouse having eight. The number of sensors in each compartment and the sensor to compartment area ratio are outlined in Table 3.5. In addition, two sensors were attached to the outside mirrors of the truck and were protected by a plastic covering to allow for air flow but also to provide protection from solar radiation. The sensors logged the external ambient temperature and humidity every minute for the duration of the journey. Sensors were not removed for the entirety of the study and care was taken to avoid contact with water when the trailer was washed out between loads. Without removing the sensors from the truck, data from the sensors were downloaded upon return from the processing plant the following day for long-haul trips and at the end of the day for short-haul trips using Thermodata software (Thermodata 3 Version 3.1.4, Embedded Data Systems, Lawrenceburg, KY, USA 40342).

Table 3.4. Logger position within the trailer with X representing distance from the left (as viewed from the rear) side wall, Y representing the height from the ground and Z representing logger distance from the front of the trailer. All values were measured in meters from point (0, 0, 0) located at the ground level on the front left corner.

Compartment	Logger	X (m)	Y (m)	Z (m)	Coordinates
Nose	1	0.15	3.18	0.60	(0.15, 3.18, 0.60)
	2	2.40	3.18	0.60	(2.40, 3.18, 0.60)
	3	1.275	3.18	1.50	(1.275, 3.18, 1.50)
	4	0.15	3.18	2.40	(0.15, 3.18, 2.40)
	5	2.40	3.18	2.40	(2.40, 3.18, 2.40)
Deck	6	0.15	4.08	3.70	(0.15, 4.08, 3.70)
	7	2.40	4.08	3.70	(2.40, 4.08, 3.70)
	8	1.275	4.08	4.60	(1.275, 4.08, 4.60)
	9	0.15	4.08	5.50	(0.15, 4.08, 4.60)
	10	2.40	4.08	5.50	(2.40, 4.08, 5.50)
	11	1.275	4.08	6.10	(1.275, 4.08, 6.10)
	12	0.15	4.08	7.00	(0.15, 4.08, 7.00)
	13	2.40	4.08	7.00	(2.40, 4.08, 7.00)
	14	1.275	4.08	7.60	(1.275, 4.08, 7.60)
	15	0.15	4.08	9.50	(0.15, 4.08, 9.50)
	16	2.40	4.08	9.50	(2.40, 4.08, 9.50)
Doghouse	17	0.15	4.08	10.70	(0.15, 4.08, 10.70)
	18	2.40	4.08	10.70	(2.40, 4.08, 10.70)
	19	1.275	4.08	11.60	(1.275, 4.08, 11.60)
	20	0.15	4.08	12.80	(0.15, 4.08, 12.80)
	21	2.40	4.08	12.80	(2.40, 4.08, 12.80)
	22	1.275	4.08	13.70	(1.275, 4.08, 13.70)
	23	0.15	4.08	15.60	(0.15, 4.08, 15.60)
	24	2.40	4.08	15.60	(2.40, 4.08, 15.60)
Belly	25	0.15	2.23	3.70	(0.15, 2.23, 3.70)
	26	2.40	2.23	3.70	(2.40, 2.23, 3.70)
	27	1.275	2.23	4.60	(1.275, 2.23, 4.60)
	28	0.15	2.23	5.50	(0.15, 2.23, 4.60)
	29	2.40	2.23	5.50	(2.40, 2.23, 5.50)
	30	1.275	2.23	6.10	(1.275, 2.23, 6.10)
	31	0.15	2.23	7.00	(0.15, 2.23, 7.00)
	32	2.40	2.23	7.00	(2.40, 2.23, 7.00)
	33	1.275	2.23	7.60	(1.275, 2.23, 7.60)
	34	0.15	2.23	9.50	(0.15, 2.23, 9.50)
	35	2.40	2.23	9.50	(2.40, 2.23, 9.50)
Back	36	0.15	2.53	10.70	(0.15, 2.53, 10.70)
	37	2.40	2.53	10.70	(2.40, 2.53, 10.70)
	38	1.275	2.53	11.60	(1.275, 2.53, 11.60)
	39	0.15	2.53	12.80	(0.15, 2.53, 12.80)
	40	2.40	2.53	12.80	(2.40, 2.53, 12.80)
	41	1.275	2.53	13.70	(1.275, 2.53, 13.70)
	42	0.15	2.53	15.60	(0.15, 2.53, 15.60)
	43	2.40	2.53	15.60	(2.40, 2.53, 15.60)

Table 3.5. Area per temperature and humidity sensor for each trailer compartment.

Compartment	Number of Sensors	Compartment Area (m^2)	Area/Sensor (m^2/sensor)
Nose	5	7.67	1.534
Deck	11	18.20	1.655
Doghouse	8	10.37	1.296
Belly	11	18.20	1.655
Back	8	14.40	1.800

Temperature and relative humidity data downloaded from the loggers were used to calculate the temperature humidity index (THI) according to the following equation as described by Mader et al. (2010)

$$THI = \left[(0.8 * \mathbf{T_{amb}}) + \left\{\left(\frac{\mathbf{RH}}{100}\right) * (\mathbf{T_{amb}} - 14.3)\right\} + 46.4\right] \quad \textbf{(3.1)}$$

where THI is unitless,

ambient temperature (T_{amb}) is in units of °C and

relative humidity (RH) is in units of %.

Further, the temperature and relative humidity data were used to determine humidity ratios for both the internal trailer environment and ambient environment using a series of equations from Albright (1990)

$$p_{ws} = \exp\left[\left(\frac{\mathbf{A_1}}{\mathbf{T}}\right) + \mathbf{A_2} + \mathbf{A_3T} + \mathbf{A_4T^2} + \mathbf{A_5T^3} + \mathbf{A_6T^4} + \mathbf{A_7}\ln\mathbf{T}\right], \textbf{(3.2)}$$

where the saturation pressure of water vapour (p_{ws}) is in units of Pa,

temperature (T) is in units of K,

$A_1 = -5.6745359 * 10^3$,
$A_2 = 6.3925247$,

$A_3 = -9.677843 * 10^{-3}$,
$A_4 = 0.622157 * 10^{-6}$,
$A_5 = 2.0747825 * 10^{-9}$,
$A_6 = -0.9484024 * 10^{-12}$ and
$A_7 = 4.1635019$.

$$p_w = \left[\frac{(\Phi * p_{ws})}{1000}\right], \tag{3.3}$$

where the partial pressure of moist air (p_w) is in units of kPa,
relative humidity (Φ) is presented as a decimal and
saturation pressure of water vapour (p_{ws}) is in units of Pa.

$$W = \left[\frac{(0.62198 * p_w)}{(p - p_w)}\right], \tag{3.4}$$

where humidity ratio (W) is in units of kg water vapour/kg dry air,
partial pressure of moist air (p_w) is in units of kPa and
atmospheric pressure is in units of kPa and is assumed to equal 101.325 kPa.

The humidity ratio is useful for this analysis because it better represents the true moisture content of the trailer environment with less effect from temperature. In this project, humidity ratio was used as an important indicator of air flow and overall ventilation of the vehicle. In the analysis however, there is still discussion of relative humidity because of its value in being easily measured directly rather than the outcome of a complex series of calculations. Ultimately, humidity ratio is useful in understanding the physics involved in ventilation of the trailer but relative humidity is a more useful tool for the industry in terms of ease of measurement and understanding.

In addition to temperature, relative humidity, THI and humidity ratio values for the inside of the trailer, delta values of these variables were created for analysis by using the difference between the inside and outside ambient conditions to describe the temperature, THI and humidity ratio lift from inside to outside the trailer.

3.2.2.2 Animal Level Microclimate

In addition to conditions at the trailer ceiling, the animal-level microclimate was also assessed. Focal heifers received an ear tag with an attached sensor (Thermochron iButton DS1921G, Maxim Integrated Products, Inc., Sunnyvale, CA, USA 94086; accuracy of ±1°C) set to record temperature in two-minute intervals for the duration of the trip. The ear tags were retrieved at the time of slaughter and the data stored on the sensors were downloaded using Thermodata software (Thermodata 3 Version 3.1.4, Embedded Data Systems, Lawrenceburg, KY, USA 40342).

Two separate temperature delta values were created for analysis. The first was created by subtracting the outside temperature from the temperature recorded at the tag level and the second by subtracting the temperature at the trailer ceiling from the temperature recorded at the tag level.

3.2.2.3 Live Weight Loss

Live weight loss, or shrink, for each compartment of animals was determined by obtaining weights before and after transport. Compartment weights were attained at loading by driving the trailer over a ground scale as each compartment was loaded and subtracting the total weight from the previous weight to get the weight of the animals in a given compartment. Each compartment of animals was weighed upon unloading at the processing facility. For long journeys, animals were moved from the deck compartment to the doghouse at the Canada/United States border to accommodate changes in axle weight requirements for each country. Due to individual animals being moved from one compartment to another at the border and because their individual weights were not known, the compartment weights after this point were unknown. As a consequence, a combined value for deck and doghouse weights and a subsequent combined value for shrink was used for analysis. Live weight loss was calculated using Equation 3.5.

$$live\ weight\ loss = \left[1 - \left(\frac{final\ weight}{initial\ weight}\right)\right] x100, \tag{3.5}$$

where live weight loss is in units of % and

initial and final weights are in units of kg.

3.2.2.4 Body Temperature

Vaginal temperatures of the focal heifers were obtained as a measure of core body temperature. Focal heifers were fitted with an intravaginal device typically used for heat synchronization in cattle. A sensor (Thermochron iButton DS1921G, Maxim Integrated Products, Inc., Sunnyvale, CA, USA 94086; accuracy of ±1°C) was attached to a hormone-free device and was inserted vaginally by an experienced veterinarian. The sensor recorded temperature in two-minute intervals for a baseline period prior to transport and for the entirety of the transport event. The sensor recorded for approximately two days prior to transport and baseline data were defined as the period of time matching the actual transport event but on the day prior to transport. This time was chosen to allow for recovery from handling on the day of sensor insertion and to account for body temperature changes due to time of day and activity of the animal on a regular day. Comparisons could then be made between vaginal temperature during transport and vaginal temperature when the animal was undergoing normal activities in the feedlot. A delta value (or the difference between transit and baseline) was created (vaginal temperature during the baseline period subtracted from vaginal temperature during transport) for each animal to account for natural variation in individual body temperatures.

3.2.3 Statistical Analysis

For the data analysis, it is important to understand the various stages of the transport event and the definitions applied to them. Transportation began as the truck left the feedlot following loading. Data collected during loading was not considered because the truck was driven from the loading chute and over a scale each time a compartment was loaded. This is not representative of common practices. Also, there were differences in the times between the last compartment loaded and the actual departure of the truck. Transportation ended upon arrival at the processing facility. This did not include the waiting time before unloading or unloading itself as precise times were not known.

Long-haul journeys all experienced at least three stops. A stop was classified based on GPS data collected from the truck and was defined as any time the vehicle reached 0 km/h and remained under 10 km/h for two or more consecutive minutes. Stops occurred at the international border and for driver rest stops in both the morning and afternoon. The stop at the border was the longest, but no longer than 24 minutes in length. Short-haul journeys did not experience any stopping.

A stabilization period of 20 minutes at the beginning of the journey was defined as the time required for microclimate variables inside the vehicle to reach a state of equilibrium.

Transit was defined as any time the vehicle was in motion following the stabilization period (or first 20 minutes of travel) and not including time periods when the vehicle was stationary.

Statistical analyses were performed using SAS statistical software (SAS Inst., Inc., Cary, NC.). Normality of the residual data was assessed using the Univariate Procedure of SAS for all mixed model and regression analyses. Due to the nature of the microclimate data, normality was assessed visually using the plots option and outlying values were removed for the final analysis.

3.2.3.1 Trailer Microclimate

The original dataset downloaded from the loggers was first assessed to determine periods of data logger failure. Any negative temperature values were removed and the logger was checked against other loggers in the same compartment. Values of relative humidity greater than 100% were set to 100% because saturation of the logger was assumed. The Univariate Procedure of SAS was used to remove any outliers from the original dataset. The resulting dataset was used for all future analyses.

The Means Procedure of SAS was used to obtain mean, minimum and maximum values as well as standard errors from the entire dataset for all microclimate variables. For delta values, only times when the vehicle was in transit were used.

The main effects of trailer compartment, plane within compartment and time of day on microclimate variables were analyzed using the Mixed Procedure of SAS. Time of day was categorized as morning (07:00-10:59), afternoon (11:00-15:59) or evening (16:00-20:59) and the original data were summarized by 10 minute averages within each of the times of day (note that the short treatment fell only within the categories of morning and afternoon). The locations of the data loggers were described in terms of compartment as well as plane within compartment. Plane was categorized as driver (left), center or passenger (right) depending on the location of the logger as viewed from behind. The long and short treatments were assessed independently. Models for the effects of compartment and plane were run separately because of spatial correlation between the two variables. The interactions between compartment, time of day and plane and time of day were included in the respective model. Analysis for delta values was conducted only on periods of time when the vehicle was in transit.

Predictive equations for internal microclimate variables given outside temperature or relative humidity were generated using the Regression Procedure of SAS. Long and short trips were considered separately to identify treatment differences. Equations were developed for the first 15 minutes following the stabilization period (or between minute 21 and 36 of transit) and the last 15 minutes prior to arrival at the processing facility. These times were chosen such that a common time existed between long and short journeys so that comparison of the equations was feasible. The stabilization period was not considered because of the instability of all microclimate variables during this time.

3.2.3.2 Animal Level Microclimate

Analysis of the animal-level microclimate was similar to that of the trailer microclimate except that the only microclimate variable considered was temperature. Two delta values were created; between the ear tag temperature and the outside and between the ear tag temperature and the ceiling temperature to describe temperature lift. A mixed model was created to assess the main effects of compartment and time of day on ear tag temperature and ear tag delta temperatures. Regression equations for ear tag temperature given outside temperature and relative humidity were created. For all analysis, long and short distances were considered separately due to multiple confounding factors.

3.2.3.3 Live Weight Loss

The percent of live weight lost was analyzed using the Mixed Procedure of SAS. The model included the main effects of treatment, compartment and their interactions.

A regression analysis was performed on the data for compartment shrink and mean compartment THI using the Reg Procedure of SAS. The analysis was performed on treatments separately.

3.2.3.4 Body Temperature

The main effects of treatment and transport event on the difference between vaginal temperature recorded during transit and during the baseline period was assessed using the Mixed Procedure of SAS. Delta values were calculated by pairing temperature recordings during transport with temperatures recorded the day before at the same time for each animal and then subtracting the two. Transport was divided into three categories for this analysis: loading, transit and arrival. Loading was defined as the first 20 minutes of transport, arrival as the last 20 minutes of transport and transit as everything in between. Data were summarized into average delta values for each event by animal. The model included the main effects of treatment, transport event and their interaction.

3.3 RESULTS

3.3.1 Trailer Microclimate

Long-haul transport ranged in duration from 715 to 740 minutes (Table 3.6). Due to a malfunction with the GPS unit, GPS data were only collected for 429 minutes for the first long-haul journey and therefore the data were analyzed only when GPS data were available. GPS data were collected for the entirety of the trip for all other journeys. All long-haul trips commenced between 07:10 and 08:31 and finished between 19:39 and 20:49 h. Short-haul transit ranged in length from 70 to 78 minutes. In order to span the day, three trips were carried out on one day and two on another. However, no data were recorded during the evening with the latest trip ending at 15:13 h.

Table 3.7 presents mean temperatures recorded at the trailer ceiling as well as mean ambient temperatures recorded on the truck mirrors. Trailer temperatures presented are for the entire journey from departure to arrival, including any stops. Ambient temperatures presented are for transit only and do not include temperatures recorded during the first 20 minutes of travel or temperatures recorded during stops. Trailer temperatures ranged from 12.2 to 39.2°C for long-hauls and 6.1 to 28.2°C for short-hauls. Mean temperature lift was positive for all loads; however values ranged from -8.4 to 9.3°C where negative values represent a time when the ambient logger was being influenced by the vehicle itself. Temperature lift values were higher for short trips conducted earlier in the day. Similarly, the mean difference between tag temperatures and ambient temperatures was also positive and had a range of values between -6.6 and 11.5°C. Again, a negative lift value in this case was the result of the ambient logger being influenced by heat generated by the vehicle.

Trailer and ambient relative humidity and relative humidity lifts are presented in Table 3.8. Short-haul transit had a narrower range of relative humidity values (41.3 to 89.4%) compared to long-haul transit (9.2 to 91.9%). Mean trailer relative humidity was quite similar to ambient relative humidity, although trailer measurements tended to be higher. The mean relative humidity lift was positive for all long-hauls and was negative only for the short-hauls conducted early in the morning (Journeys 1 and 4). The relative humidity lift ranged from -12.7 to 31.9% for both distances where a negative value represents a condition where the ambient environment is more humid. Such conditions were experienced first thing in the morning shortly after the trailer had been loaded.

Mean trailer THI ranged from 54.3 to 85.1 for long distance transport compared to 44.2 to 75.0 for short distance (Table 3.9). The mean THI lift was positive and greater than 2 for both treatments. Negative values for THI lift were recorded for all journeys except one short trip.

Table 3.10 presents mean humidity ratios for inside and outside the trailer. Mean trailer humidity ratio was always greater than mean ambient humidity ratio and ranged from 2.6 to 14.9 g water/kg air for long journeys and 4.5 to 10.2 g water/kg air for short journeys. The mean humidity ratio lift was higher in long-hauls, averaging 1.9 g water/kg air, compared to short-hauls, averaging 1.3 g water/kg air.

The temperature, relative humidity, THI and humidity ratio over the course of an average long and short-haul journey is presented in Figures 3.1 and 3.2, respectively. The average ambient temperature for short-hauls was lower than the average ambient temperature for long-hauls (Figure 3.2) so two figures for short-haul microclimate variables were created; one for an average short journey and one for a short journey conducted at temperatures comparable to the average long-haul journey. The microclimate variables over the course of a short journey comparable to an average long journey are presented in Figure 3.3. For the long journey, in general, temperature and THI increase as the elapsed time increases. Relative humidity decreases over the course of the trip and humidity ratio increased at the end of the trip. For both the median short-haul trip (Journey 5) and the short-haul trip most comparable to the long journey (Journey 3), temperature and THI remain relatively constant throughout the journey. Relative humidity and the humidity ratio started high and decreased for short Journey 5, whereas relative humidity remained stable and the humidity ratio fluctuated for short Journey 3.

The difference between microclimate variables inside and outside the trailer over time is presented in Figures 3.4 to 3.6, respectively. Positive lift values indicate that conditions recorded inside the trailer are greater than the ambient conditions recorded on the mirrors. For example, positive temperature lift values indicate that the trailer ceiling is warmer than the outside. Similarly, positive humidity ratio lift values indicate that the air inside the trailer contains more moisture per kilogram than the air outside the trailer. Figure 3.4 illustrates the behaviour of the various lift values for microclimate variables for an average long-haul trip. Both temperature and THI lifts generally remain positive and decrease slightly as transit progresses. Negative values were observed during loading and at times when the vehicle was stationary. The humidity ratio lift is quite variable but always positive indicating the moisture levels inside the trailer are greater than outside. There is a tendency for the humidity ratio lift to be highest midway through the journey. Relative humidity inside the trailer is approximately 10 to 15% higher than the relative humidity outside at the beginning of transit but decreases rapidly within the first half hour. After this point, the relative humidity lift remains variable but tends to increase through the afternoon. Peaks in the humidity ratio lift and the relative humidity lift occurred during stationary periods. The lift values during stationary periods are illustrated further in Figure 3.8. Figures 3.5 and 3.6 illustrate the lift values over time for short-haul transit. These figures clearly show the stabilization that occurs in the first 20 minutes of transit. For short-haul Journey 3, negative values for temperature and THI lifts occur at the beginning of the trip. Short-haul Journey 5 shows large decreases in humidity ratio and relative humidity lifts in the first 20 minutes. After this time, all microclimate variable lifts equilibrate to some degree above outside conditions.

The effect of stationary periods on microclimate lift values is presented in Figure 3.8. In this example, the vehicle was stationary twice, from 497 to 504 minutes and from 518 to 520 minutes. The stops are represented by two corresponding peaks in the data. Following stopping, humidity ratio and relative humidity increase inside the vehicle relative to the outside. The temperature lift is seen to decrease, meaning that the difference between the inside temperature and the outside temperature has become smaller. THI follows the same pattern as it is calculated, in part, from temperature. As the vehicle returns to motion, all variables return to pre-stationary levels.

A comparison of the first 45 minutes of transit for both a long and a short journey is presented in Figure 3.7. The two trips were conducted under similar conditions. Microclimate lifts behave similarly for both transport distances, with the exception of relative humidity. The decrease in the relative humidity lift is more pronounced for the long-haul journey.

Table 3.6. Journey dates and durations.

Transport Distance		Date	Duration (min)	Start Time	End Time	Number of Stops
Long (940 km)						
	Journey 1*	July 29	429	07:10	14:19	3
	Journey 2	July 31	740	07:23	19:43	4
	Journey 3	August 5	725	07:34	19:39	4
	Journey 4	August 7	738	08:31	20:49	5
	Journey 5	August 12	715	08:15	20:10	7
Short (85 km)						
	Journey 1	October 3	75	08:06	09:21	0
	Journey 2	October 3	75	11:00	12:15	0
	Journey 3	October 3	75	13:58	15:13	0
	Journey 4	October 6	70	08:28	09:38	0
	Journey 5	October 6	78	11:29	12:47	0

*Data presented only for time when GPS unit was functioning.

Table 3.7. Mean and range of trailer, ambient and lift temperature (T, °C) values by distance and journey.
[1]For entire journey, including stabilization and stationary periods.

Transport Distance	Mean Trailer T[1] (°C)	Trailer T Range[1] (°C)	Mean Ambient T[2] (°C)	Ambient T Range[2] (°C)	Mean T Lift[2] (°C)	Range T Lift[2] (°C)	Mean Tag Lift[1,3] (°C)	Range Tag Lift[1,3] (°C)
Long (940 km)								
Journey 1	22.71 ± 0.031	12.20-33.70	20.46 ± 0.034	12.15-29.90	2.25 ± 0.011	-4.20-8.50	3.50 ± 0.037	-1.65-8.60
Journey 2	24.53 ± 0.034	13.10-36.20	22.89 ± 0.038	11.90-33.90	1.82 ± 0.008	-7.80-8.80	3.13 ± 0.042	-4.90-11.35
Journey 3	27.00 ± 0.041	12.70-39.20	25.82 ± 0.046	12.65-39.60	1.35 ± 0.010	-8.40-9.30	1.68 ± 0.034	-6.60-8.10
Journey 4	29.99 ± 0.029	16.60-37.70	28.93 ± 0.033	18.90-38.85	1.19 ± 0.008	-7.65-8.65	1.14 ± 0.029	-5.90-7.60
Journey 5	25.79 ± 0.032	12.70-38.70	24.10 ± 0.036	13.65-33.40	1.73 ± 0.008	-6.55-7.80	NA	NA
Short (85 km)								
Journey 1	14.53 ± 0.022	11.20-18.60	11.69 ± 0.017	10.60-13.40	3.06 ± 0.023	0.20-5.60	4.58 ± 0.103	1.40-9.85
Journey 2	21.97 ± 0.026	18.10-24.70	21.20 ± 0.014	19.40-21.90	1.41 ± 0.021	-3.55-3.55	1.73 ± 0.128	-4.45-6.55
Journey 3	24.85 ± 0.018	20.10-28.20	23.47 ± 0.014	22.90-24.70	1.32 ± 0.019	-3.35-2.80	1.96 ± 0.062	-0.70-4.55
Journey 4	9.92 ± 0.023	6.10-14.20	6.59 ± 0.018	5.10-7.60	3.17 ± 0.029	-0.50-6.00	4.47 ± 0.112	1.15-9.65
Journey 5	15.39 ± 0.031	12.10-21.70	12.41 ± 0.007	11.90-13.15	2.35 ± 0.026	-0.45-6.80	5.11 ± 0.197	0.35-11.30

[2]For transit only.
[3]Tag lift values = tag temperature – outside temperature, during transit only.

Table 3.8. Mean and range of trailer, ambient and lift relative humidity (RH, %) values by distance and journey.[1]

Transport Distance	Mean Trailer RH (%)	Trailer RH Range (%)	Mean Ambient RH (%)	Ambient RH Range (%)	Mean RH Lift (%)	Range RH Lift (%)
Long (940 km)						
Journey 1	49.21 ± 0.130	30.23-91.87	44.38 ± 0.139	20.65-83.80	4.15 ± 0.210	-6.08-22.24
Journey 2	33.80 ± 0.096	9.24-77.55	27.60 ± 0.096	4.60-70.35	5.78 ± 0.155	-10.07-26.09
Journey 3	39.46 ± 0.126	11.00-91.19	32.59 ± 0.130	6.40-85.20	6.21 ± 0.160	-2.36-24.56
Journey 4	36.61 ± 0.093	17.53-77.23	30.59 ± 0.093	10.20-66.05	5.93 ± 0.132	-3.17-17.96
Journey 5	40.13 ± 0.093	21.67-79.73	35.67 ± 0.094	15.60-72.45	4.21 ± 0.130	-3.81-31.23
Short (85 km)						
Journey 1	82.86 ± 0.094	78.37-89.42	89.81 ± 0.052	86.60-94.85	-6.81 ± 0.361	-11.85-0.07
Journey 2	57.18 ± 0.141	49.65-64.20	51.11 ± 0.094	46.35-60.80	3.02 ± 0.294	-1.78-8.47
Journey 3	44.45 ± 0.215	41.34-46.93	38.83 ± 0.027	36.35-40.70	6.92 ± 0.241	4.54-11.85
Journey 4	78.71 ± 0.150	67.38-88.26	82.15 ± 0.197	70.65-94.60	-6.68 ± 0.358	-12.68- -0.43
Journey 5	50.53 ± 0.198	44.23-72.31	40.50 ± 0.041	38.00-44.05	9.81 ± 0.931	2.38-31.91

[1] All variables presented over the entire journey including stabilization and stationary periods.

Table 3.9. Mean and range of trailer, ambient and lift temperature humidity index (THI) values by distance and journey.

Transport Distance	Mean Trailer THI[1]	Trailer THI Range[1]	Mean Ambient THI[2]	Ambient THI Range[2]	Mean THI Lift[2]	Range THI Lift[2]
Long (940 km)						
Journey 1	68.06 ± 0.033	54.28-79.92	64.77 ± 0.037	54.34-73.65	3.25 ± 0.013	-2.03-10.93
Journey 2	68.74 ± 0.031	55.86-81.91	66.20 ± 0.034	54.23-76.75	2.61 ± 0.008	-3.99-10.37
Journey 3	71.65 ± 0.039	55.00-85.12	69.27 ± 0.042	55.20-80.18	2.46 ± 0.010	-5.35-11.78
Journey 4	75.40 ± 0.023	61.38-83.25	73.20 ± 0.027	64.18-80.70	2.31 ± 0.008	-4.09-12.79
Journey 5	70.89 ± 0.032	55.00-84.52	68.34 ± 0.036	56.85-78.46	2.52 ± 0.009	-4.49-10.04
Short (85 km)						
Journey 1	58.15 ± 0.036	52.46-65.35	53.39 ± 0.031	51.37-56.34	5.12 ± 0.036	0.32-8.68
Journey 2	68.28 ± 0.030	63.41-71.85	66.86 ± 0.013	65.02-67.52	2.07 ± 0.027	-3.82-4.65
Journey 3	70.89 ± 0.020	66.57-75.04	68.74 ± 0.014	68.09-69.94	2.17 ± 0.024	-1.63-6.60
Journey 4	50.82 ± 0.040	44.15-57.68	45.28 ± 0.044	41.78-47.75	5.42 ± 0.052	-1.30-10.97
Journey 5	59.29 ± 0.043	54.05-68.56	55.56 ± 0.008	54.90-56.48	2.85 ± 0.033	-1.52-8.68

[1] For entire journey, including stabilization and stationary periods.
[2] For transit only.

Table 3.10. Mean and range of trailer, ambient and lift humidity ratio (W, g water/kg air) values by distance and journey.[1]

Transport Distance	Mean Trailer W (g/kg)	Trailer W Range (g/kg)	Mean Ambient W (g/kg)	Ambient W Range (g/kg)	Mean W Lift (g/kg)	Range W Lift (g/kg)
Long (940 km)						
Journey 1	8.04 ± 0.045	6.50-12.54	6.21 ± 0.038	4.66-7.99	1.83 ± 0.032	1.05-5.37
Journey 2	5.93 ± 0.048	2.60-10.17	4.19 ± 0.042	1.23-7.21	1.74 ± 0.028	-0.46-6.21
Journey 3	7.66 ± 0.058	4.35-12.61	5.51 ± 0.057	2.46-9.41	2.15 ± 0.037	0.50-6.78
Journey 4	8.95 ± 0.059	6.05-14.88	6.76 ± 0.059	3.93-12.93	2.20 ± 0.026	1.12-6.74
Journey 5	7.79 ± 0.043	6.15-13.64	6.14 ± 0.037	1.51-12.37	1.65 ± 0.024	0.32-4.82
Short (85 km)						
Journey 1	8.52 ± 0.047	7.70-9.58	7.55 ± 0.034	7.06-8.29	0.97 ± 0.059	0.30-2.47
Journey 2	9.36 ± 0.052	8.65-10.20	8.15 ± 0.048	7.34-8.95	1.22 ± 0.034	0.36-1.98
Journey 3	8.63 ± 0.025	8.24-8.99	6.90 ± 0.023	6.55-7.26	1.73 ± 0.023	1.36-2.18
Journey 4	5.95 ± 0.070	5.13-6.82	5.14 ± 0.047	4.52-5.86	0.81 ± 0.029	0.47-1.40
Journey 5	5.50 ± 0.140	4.50-9.43	3.59 ± 0.014	3.38-3.85	1.91 ± 0.142	0.83-5.92

[1] All variables presented over the entire journey including stabilization and stationary periods.

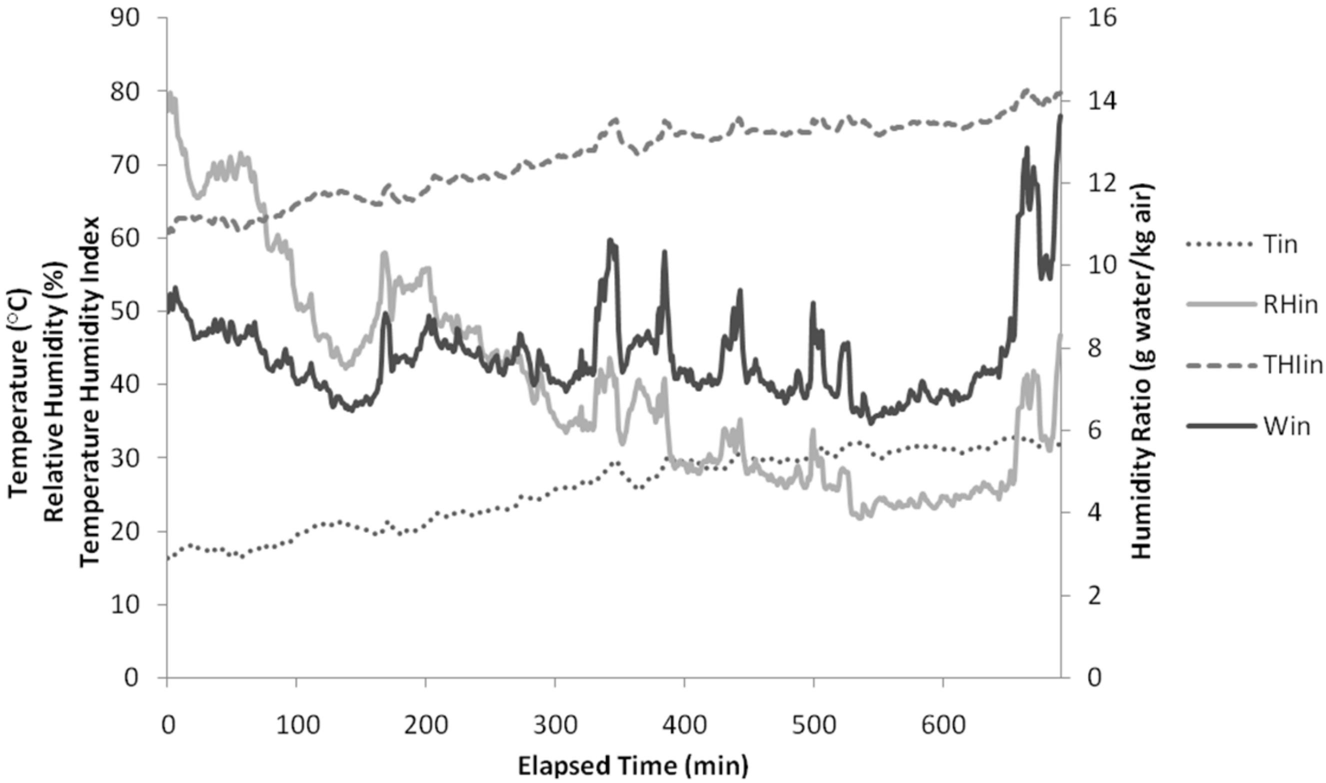


Figure 3.1. Trailer microclimate variables over time for long-haul Journey 5. T_{in} is internal trailer temperature (°C), RH_{in} is internal trailer relative humidity (%), THI_{in} is internal trailer temperature humidity index and W_{in} is internal trailer humidity ratio (g water/kg air).

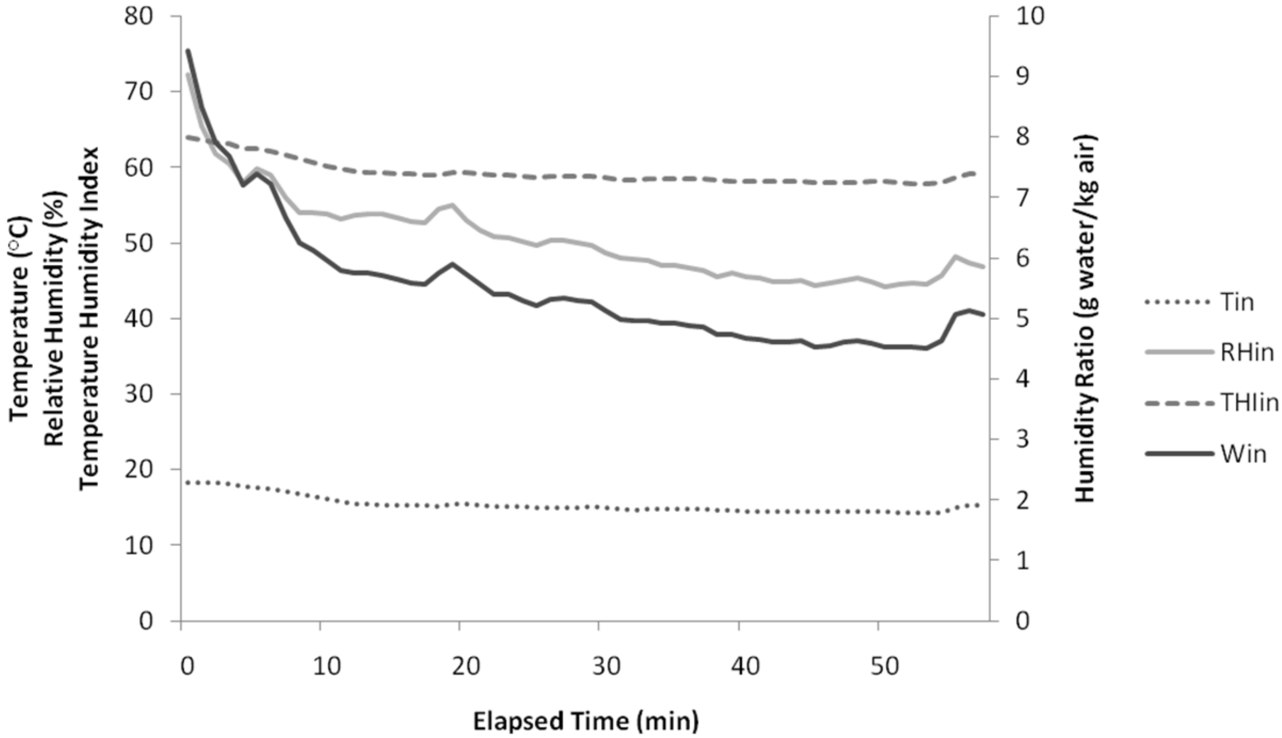


Figure 3.2. Trailer microclimate variables over time for short-haul Journey 5. T_{in} is internal trailer temperature (°C), RH_{in} is internal trailer relative humidity (%), THI_{in} is internal trailer temperature humidity index and W_{in} is internal trailer humidity ratio (g water/kg air).

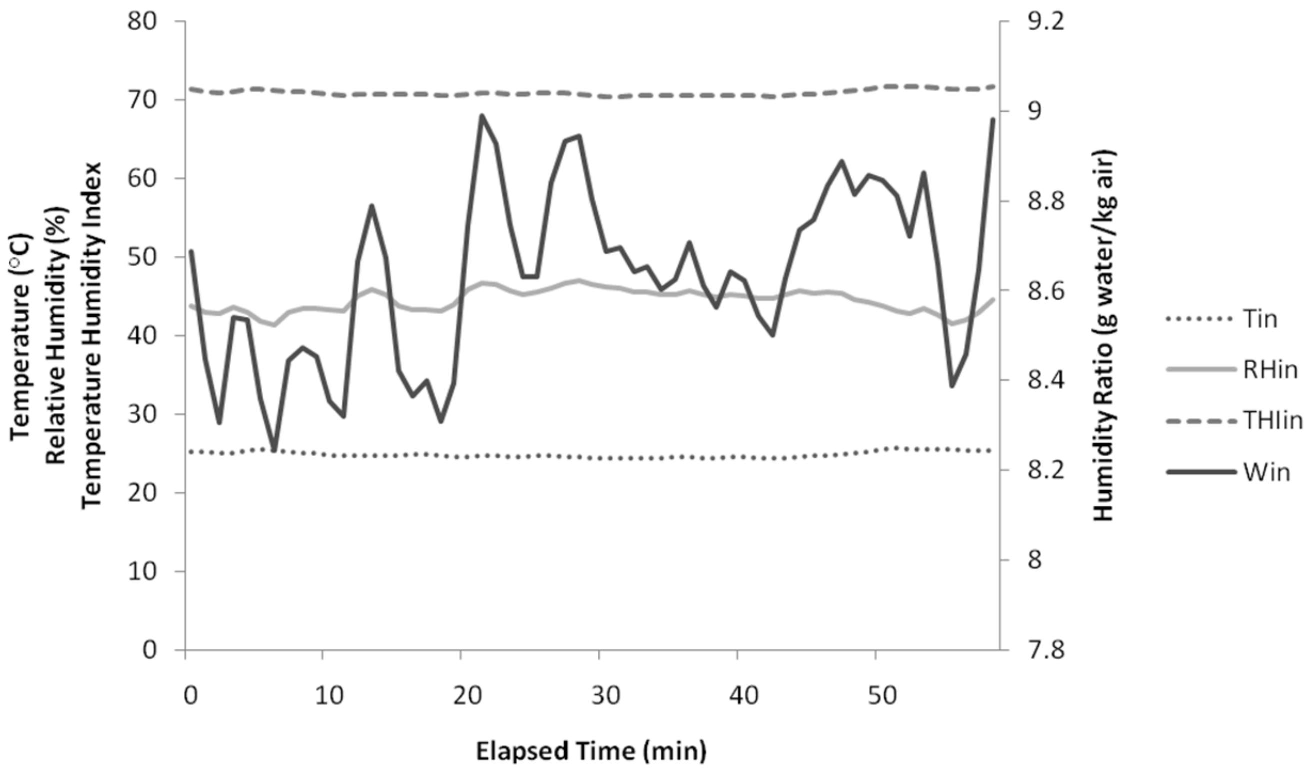


Figure 3.3. Trailer microclimate variables over time for short-haul Journey 3 (comparable temperature to long Journey 5). T_{in} is internal trailer temperature (°C), RH_{in} is internal trailer relative humidity (%), THI_{in} is internal trailer temperature humidity index and W_{in} is internal trailer humidity ratio (g water/kg air).

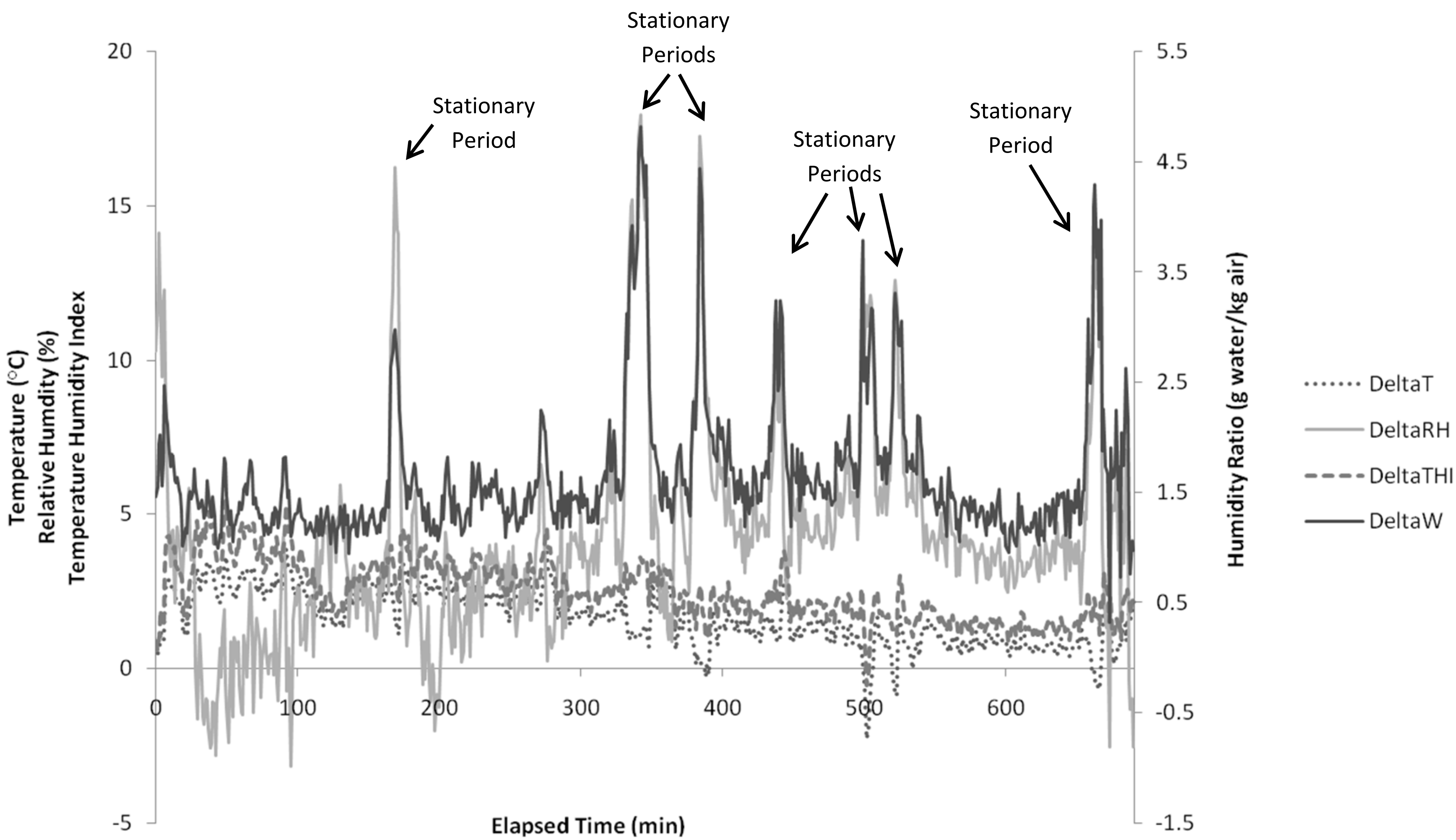


Figure 3.4. Lift values over time for long-haul Journey 5. DeltaT is the temperature lift measured between the outside and inside of the trailer (°C), DeltaRH is the relative humidity lift measured between the outside and inside of the trailer (%), DeltaTHI is the temperature humidity index lift measured between the outside and inside of the trailer and DeltaW is the humidity ratio lift measured between the outside and inside of the trailer (g water/kg air).

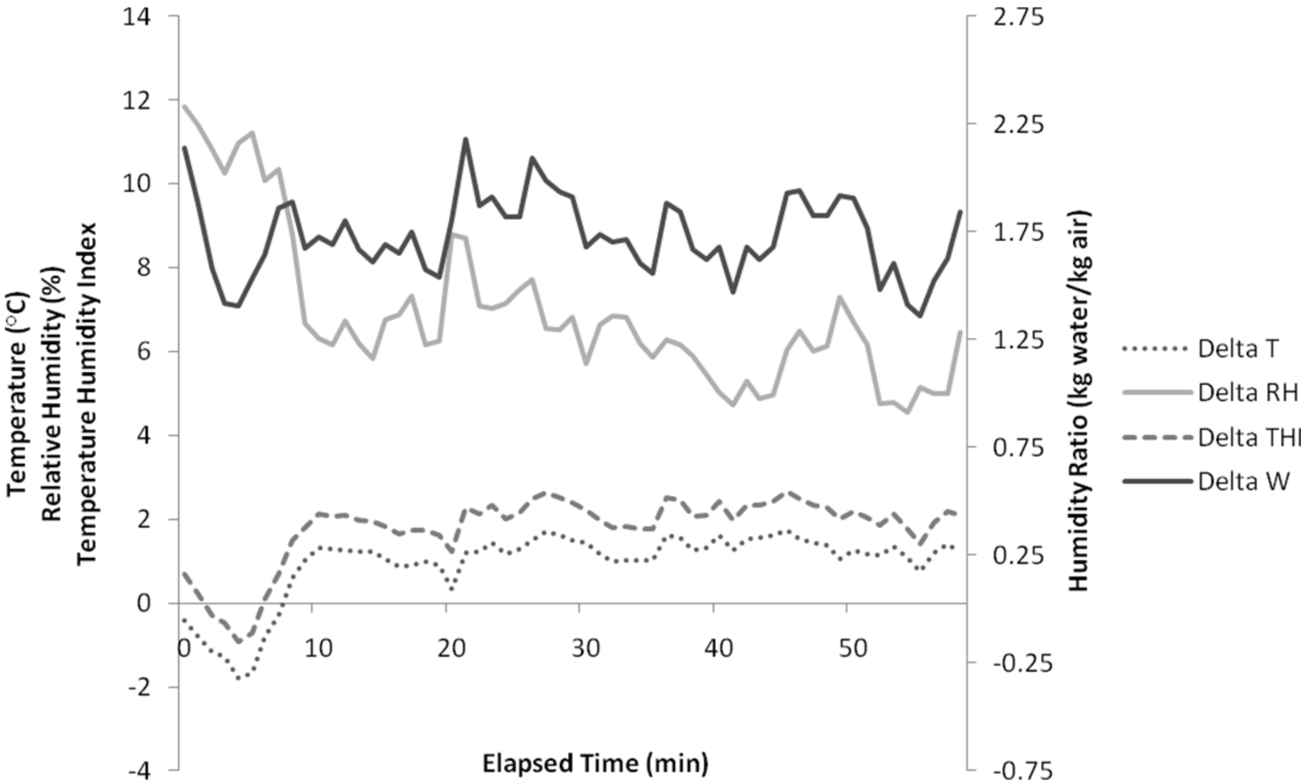


Figure 3.5. Lift values over time for short-haul Journey 3. DeltaT is the temperature lift measured between the outside and inside of the trailer (°C), DeltaRH is the relative humidity lift measured between the outside and inside of the trailer (%), DeltaTHI is the temperature humidity index lift measured between the outside and inside of the trailer and DeltaW is the humidity ratio lift measured between the outside and inside of the trailer (g water/kg air).

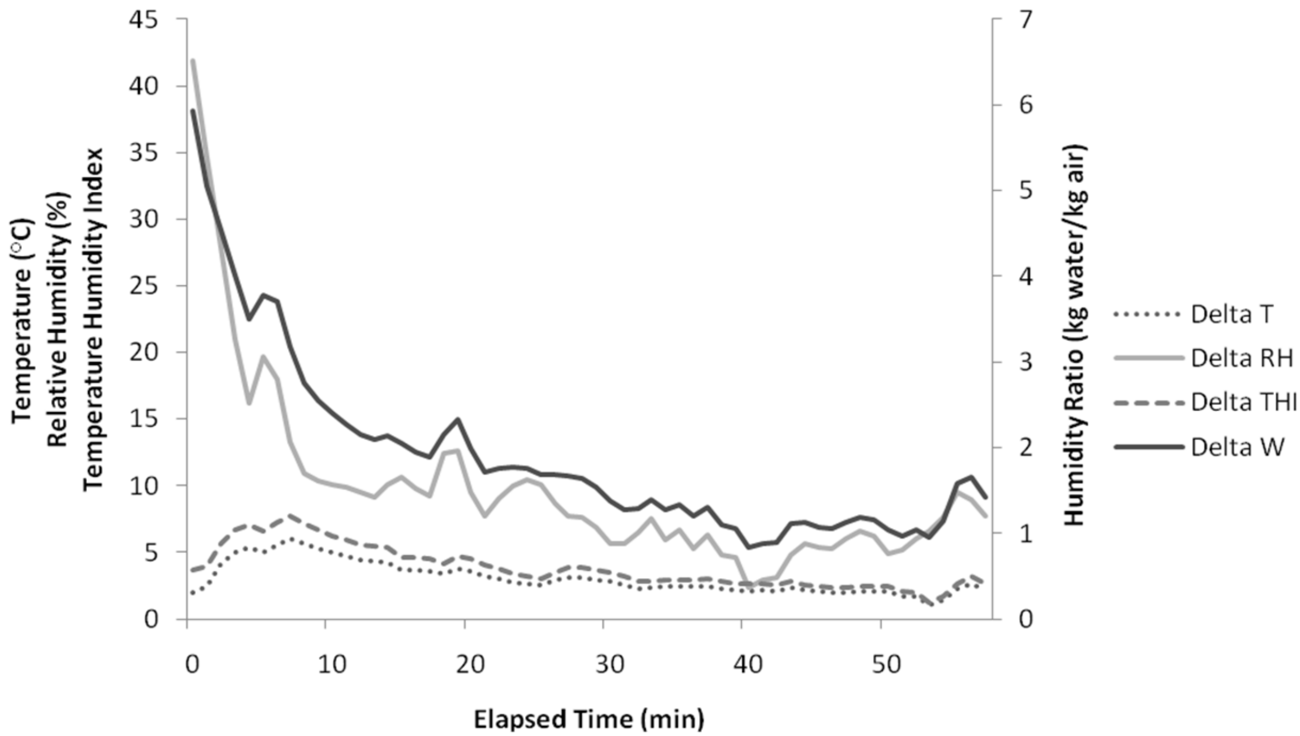
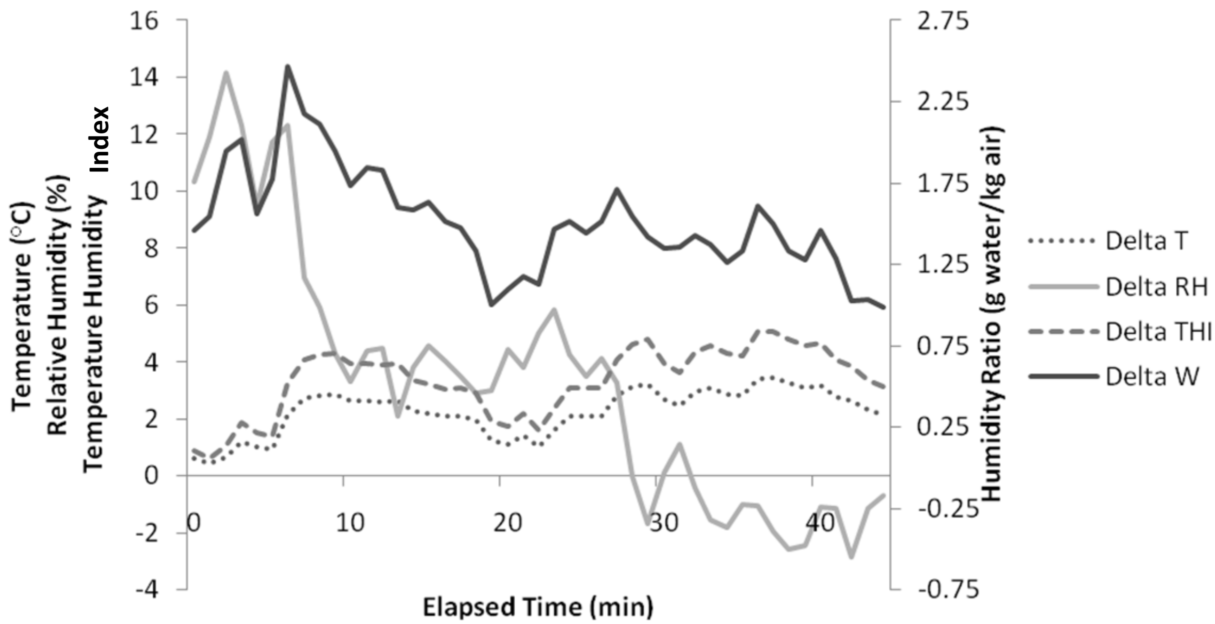


Figure 3.6. Lift values over time for short-haul Journey 5. DeltaT is the temperature lift measured between the outside and inside of the trailer (°C), DeltaRH is the relative humidity lift measured between the outside and inside of the trailer (%), DeltaTHI is the temperature humidity index lift measured between the outside and inside of the trailer and DeltaW is the humidity ratio lift measured between the outside and inside of the trailer (g water/kg air).

A) Long-Haul Journey



B) Short-Haul Journey

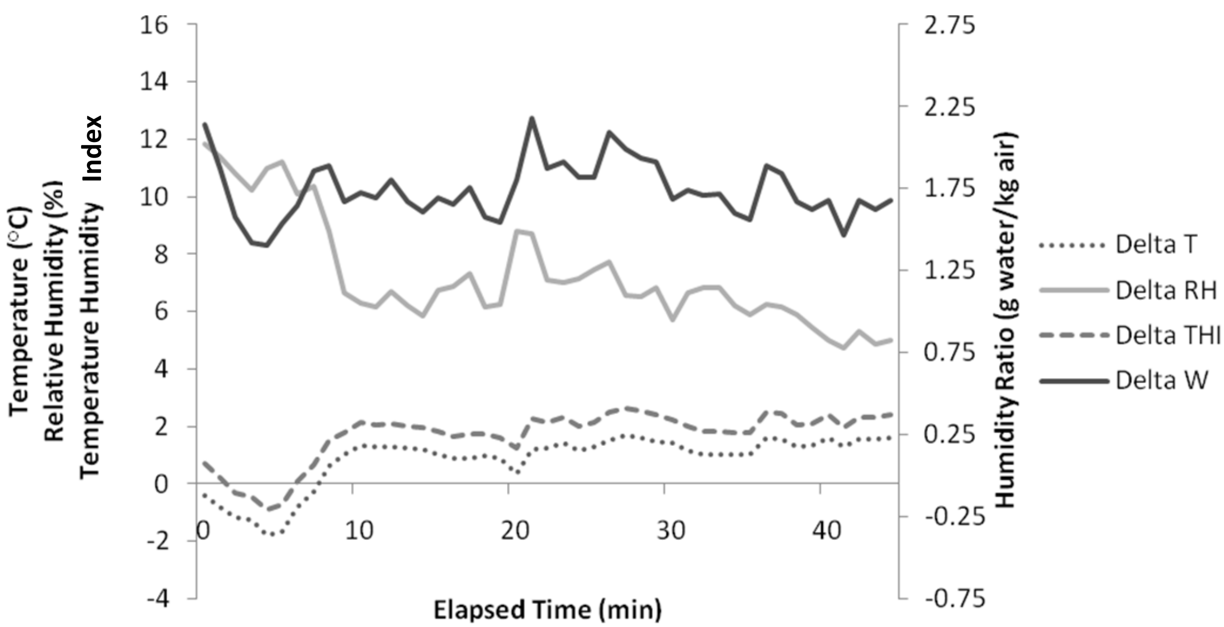


Figure 3.7. Comparing the first 45 minutes for a long and a short journey. DeltaT is the temperature lift measured between the outside and inside of the trailer (°C), DeltaRH is the relative humidity lift measured between the outside and inside of the trailer (%), DeltaTHI is the temperature humidity index lift measured between the outside and inside of the trailer and DeltaW is the humidity ratio lift measured between the outside and inside of the trailer (g water/kg air).

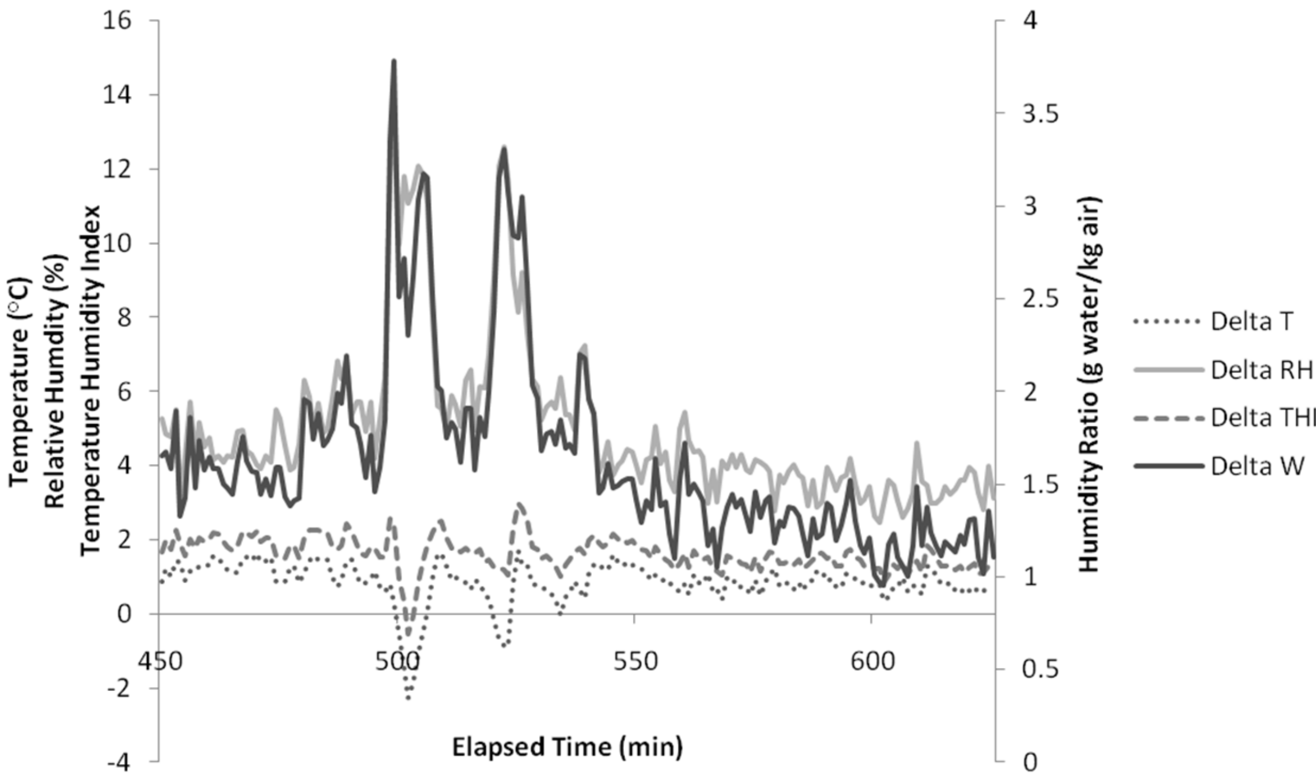


Figure 3.8. The effect of stopping on microclimate variables for long-haul Journey 5. DeltaT is the temperature lift measured between the outside and inside of the trailer (°C), DeltaRH is the relative humidity lift measured between the outside and inside of the trailer (%), DeltaTHI is the temperature humidity index lift measured between the outside and inside of the trailer and DeltaW is the humidity ratio lift measured between the outside and inside of the trailer (g water/kg air).

For all long-haul microclimate variables, the interaction between trailer compartment and time of day was significant ($P < 0.001$). The compartment and time of day interaction was not significant ($P \geq 0.05$) for any short-haul microclimate variables. Mean trailer temperature and mean trailer THI differed by time of day ($P < 0.001$) but not compartment ($P \geq 0.05$) for the short-haul treatment. Both time of day ($P < 0.001$) and compartment ($P = 0.015$) affected mean trailer relative humidity for short trips with the deck and doghouse compartments in the afternoon having the lowest relative humidity values. Mean trailer humidity ratio for short-haul journeys was the only microclimate variable not affected ($P \geq 0.05$) by either compartment or time of day.

The interaction between trailer compartment and time of day was significant for temperature lift during long-haul transport ($P < 0.001$; Figure 3.9). Temperature lift values were highest in the morning and decreased with time of day, with the lowest values in the evening. In general, the nose, deck and doghouse had higher temperature lift values than the belly and the back. Temperature lift values were greatest in the nose in the morning period but were less than the deck and doghouse in the afternoon and evening periods. The lower-level compartments (belly and back) had consistently lower temperature lift values.

Temperature lift was affected by compartment ($P < 0.001$; Figure 3.12) and time of day ($P < 0.001$) for the short-haul treatment. The nose compartment was significantly higher than the back, belly and doghouse compartments. The difference between inside and ambient temperature was higher in the morning compared to the afternoon ($P < 0.05$) for all compartments.

A trailer plane by time of day interaction significantly affected temperature lift for long journeys ($P < 0.001$; Figure 3.15). As seen in the compartment and time of day analysis, temperature lift is highest in the morning followed by the afternoon and then the evening. In the morning period the center plane had a higher temperature lift than the right plane ($P < 0.001$) however, there was no difference ($P \geq 0.05$) in temperature lift between the center and left planes. Temperature lift differences between the planes disappear as the day progresses. This is likely because the trailer was cool after being empty at night and warmed during the day with solar radiation. Since the trailer traveled primarily south for all long-haul journeys, it is reasonable to believe that the solar effects were greater on the right side of the trailer. Although there was not a significant interaction, temperature lift was affected by plane (Figure 3.18) and time of day independently for short-haul journeys ($P < 0.001$ for both). Similar to the long-haul treatment, the center plane was the highest. However, unlike the long treatment, the difference in plane for short-hauls was between the center plane and the left plane. This was likely due to the effect of solar radiation and the prevalent direction of travel.

The interaction between trailer compartment and time of day was significant for THI lift in the long-haul treatment ($P < 0.001$; Figure 3.10). THI lift was greatest in the morning and decreased throughout the day. Within a time period, the nose compartment was always the highest and generally the deck and doghouse were greater than the back and belly. The THI lift in the nose compartment was also the highest for short journeys ($P < 0.001$; Figure 3.13).

A significant trailer plane by time of day interaction was observed ($P < 0.001$; Figure 3.16) for THI lift in the long-haul treatment. These differences were basically the same as those observed for temperature lift in the same treatment. The center plane was higher than the passenger plane for the morning period ($P < 0.001$), with the differences becoming less pronounced over time. The short treatment also showed differences by plane ($P < 0.001$; Figure

3.19) and time of day ($P < 0.001$) with the center and passenger planes being greater than the driver ($P < 0.001$) and the morning being greater than the afternoon ($P < 0.001$).

The interactions between compartment and time of day and plane and time of day were significant ($P < 0.001$ for both) for the long-haul humidity ratio lift. Unlike the other lift values for microclimate, the humidity ratio lift was slightly higher in the afternoon ($P < 0.001$) and lowest in the morning ($P < 0.001$) (Figure 3.11). Within a time period, the nose was consistently highest ($P < 0.001$) and the back and belly were higher than the deck or doghouse ($P < 0.001$).

For short-haul trips, compartment significantly affected the humidity ratio lift ($P < 0.001$; Figure 3.14) with the nose having higher values than the back, deck or doghouse compartments. Generally, the humidity ratio lift in the back and belly compartments was greater than in the deck and doghouse compartments. Time of day also significantly affected the humidity ratio lift ($P < 0.001$). The afternoon had higher lift values than the morning. There was no effect of plane on the humidity ratio lift for short-hauls ($P = 0.368$).

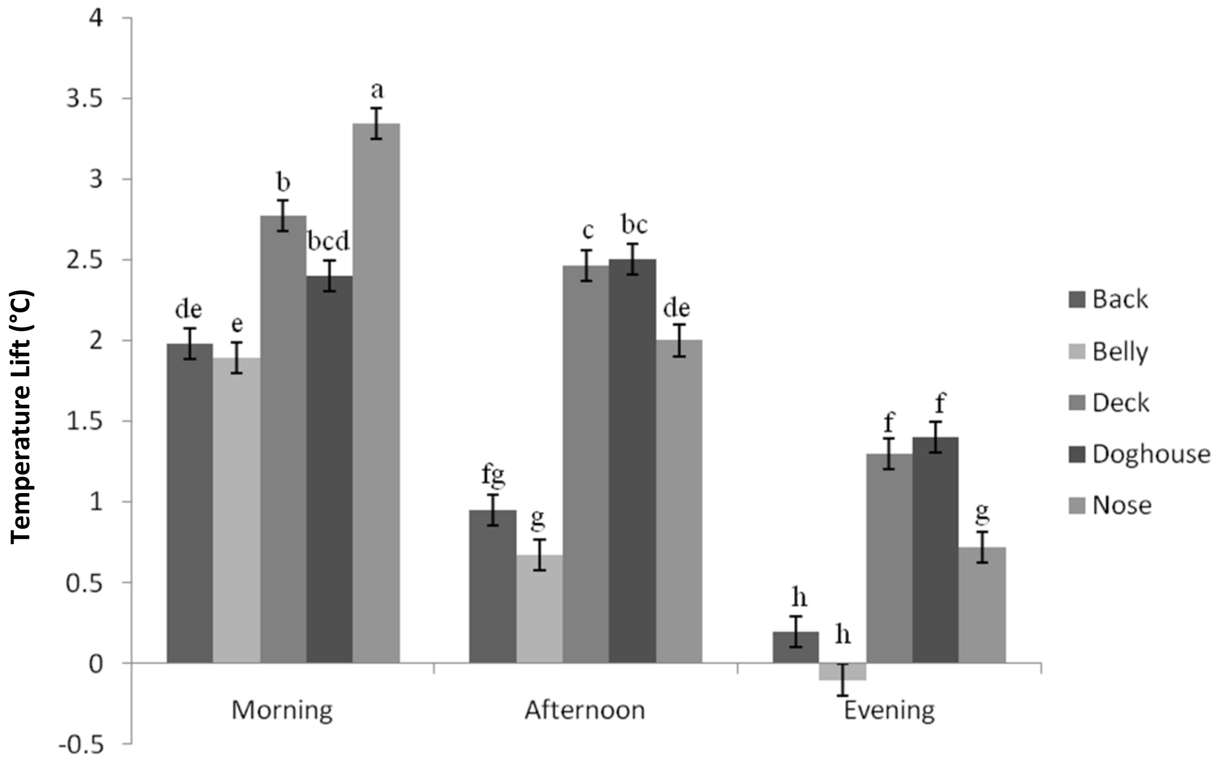


Figure 3.9. Interaction between compartment and time of day on the temperature lift for long-haul journeys ($P < 0.001$).

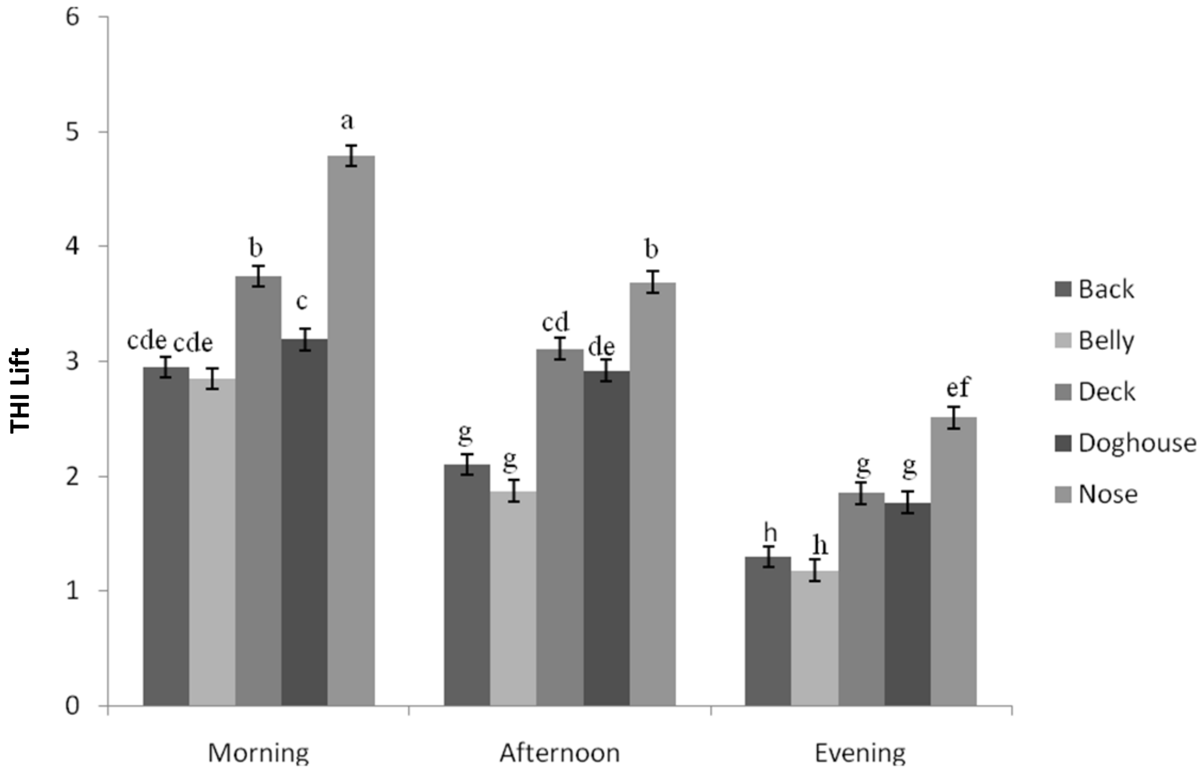


Figure 3.10. Interaction between compartment and time of day on the THI lift for long-haul journeys (*P* < 0.001).

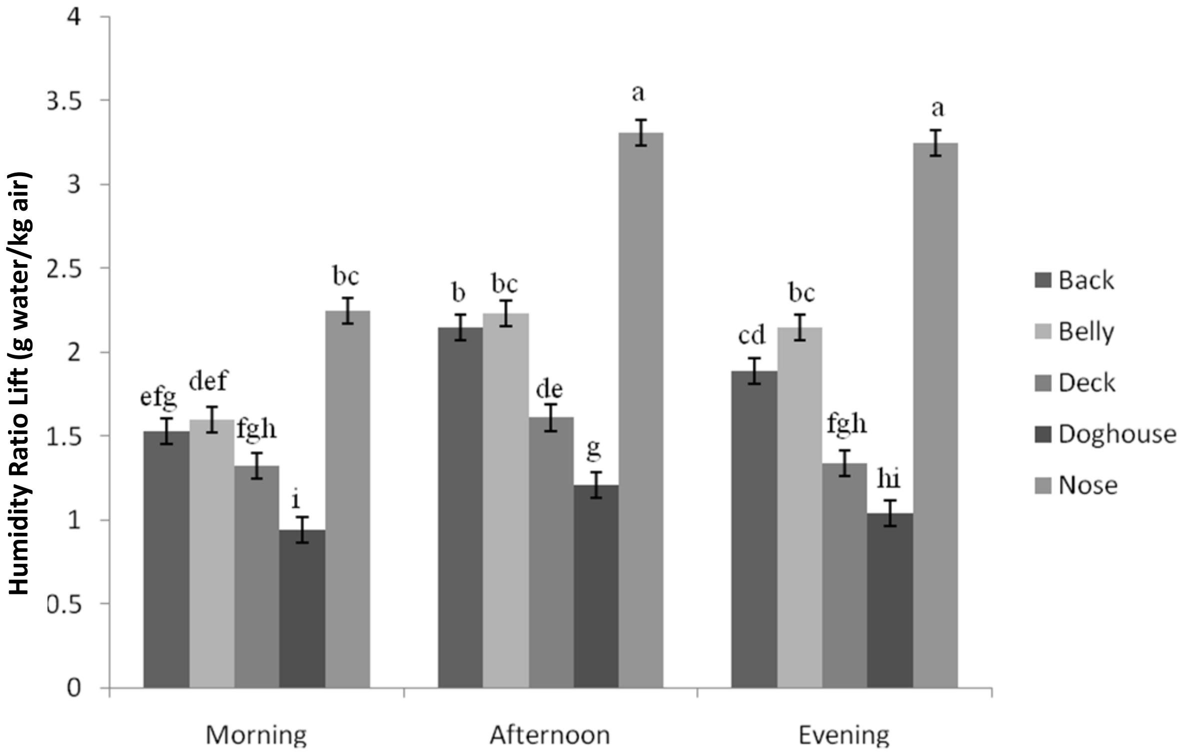


Figure 3.11. Interaction between compartment and time of day on the humidity ratio lift for long-haul journeys ($P < 0.001$).

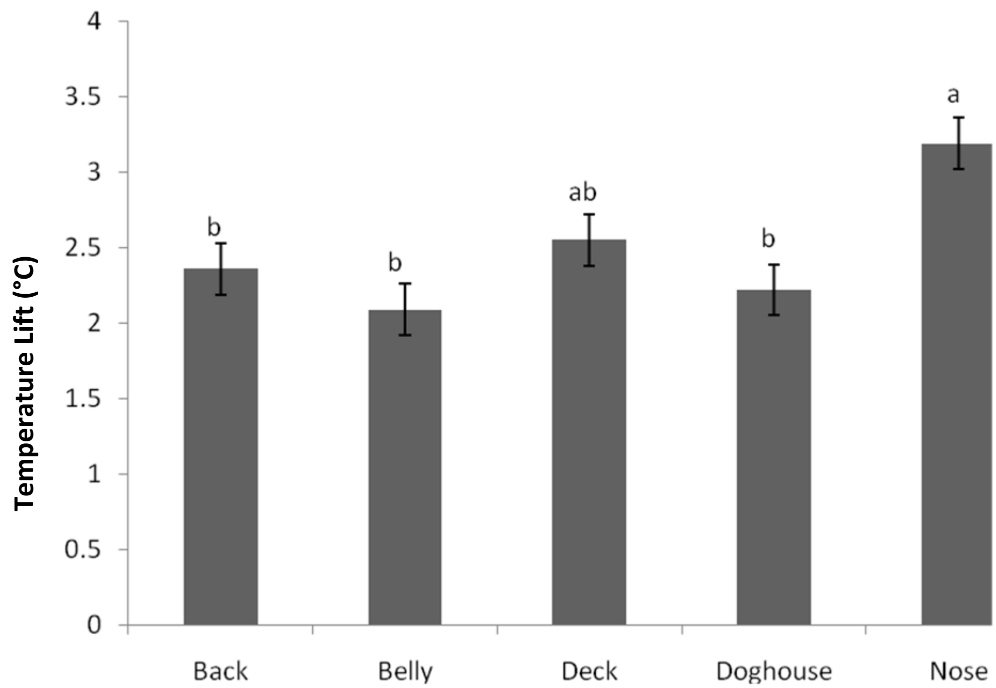


Figure 3.12. Effect of trailer compartment on the temperature lift for short-haul treatment (*P* < 0.001).

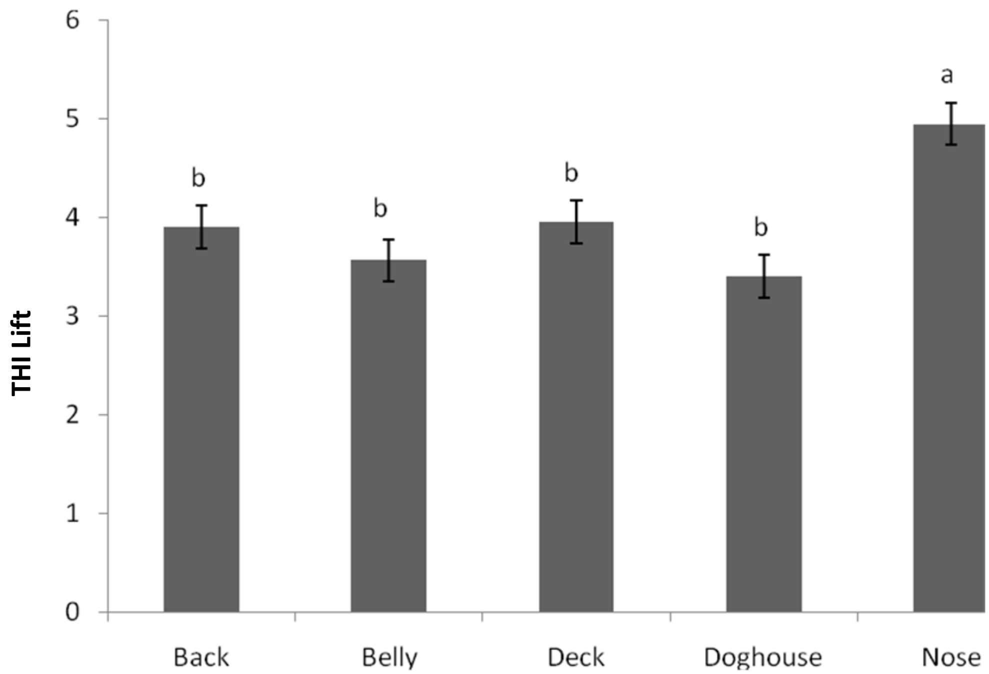


Figure 3.13. Effect of trailer compartment on the THI lift for short-haul treatment ($P < 0.001$).

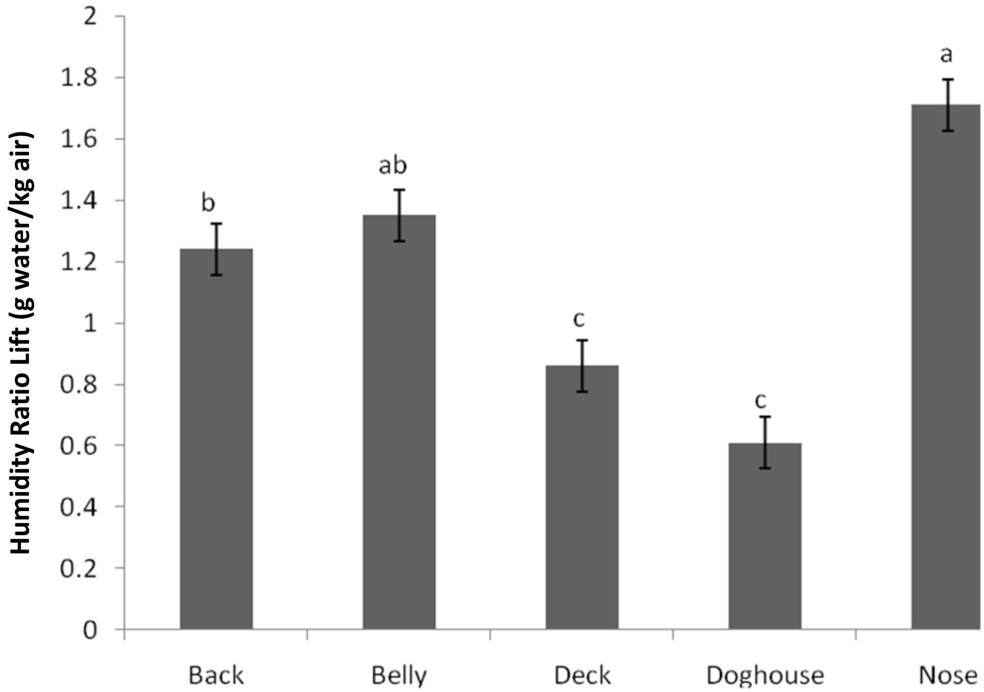


Figure 3.14. Effect of trailer compartment on the humidity ratio lift for short-haul treatment ($P < 0.001$).

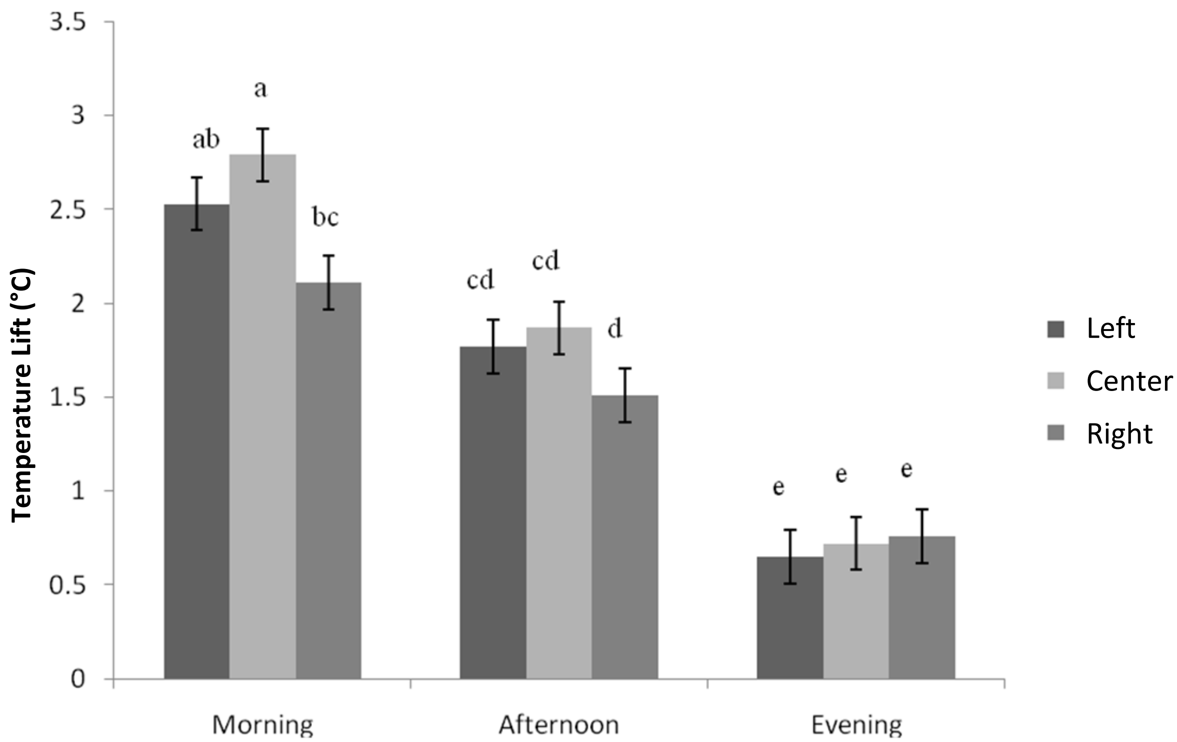


Figure 3.15. Effect of trailer plane and time of day on the temperature lift for long-haul treatment (*P* < 0.001).

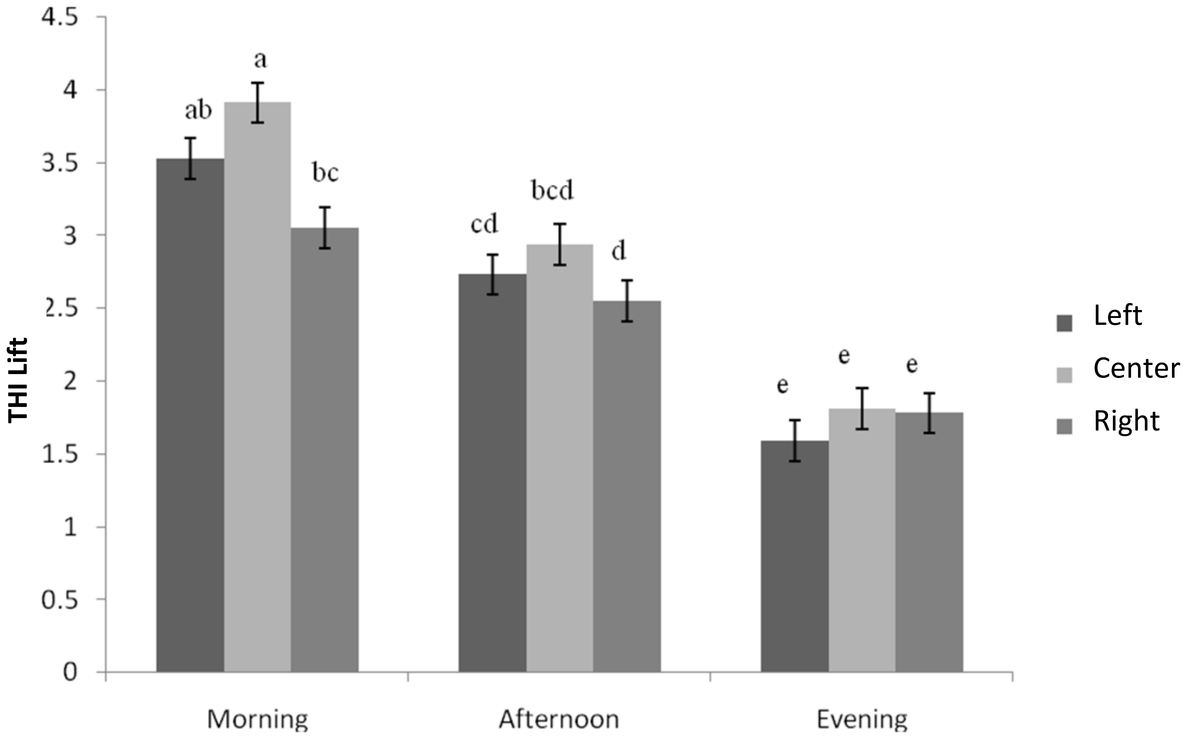


Figure 3.16. Effect of trailer plane and time of day on the THI lift for long-haul treatment ($P < 0.001$).

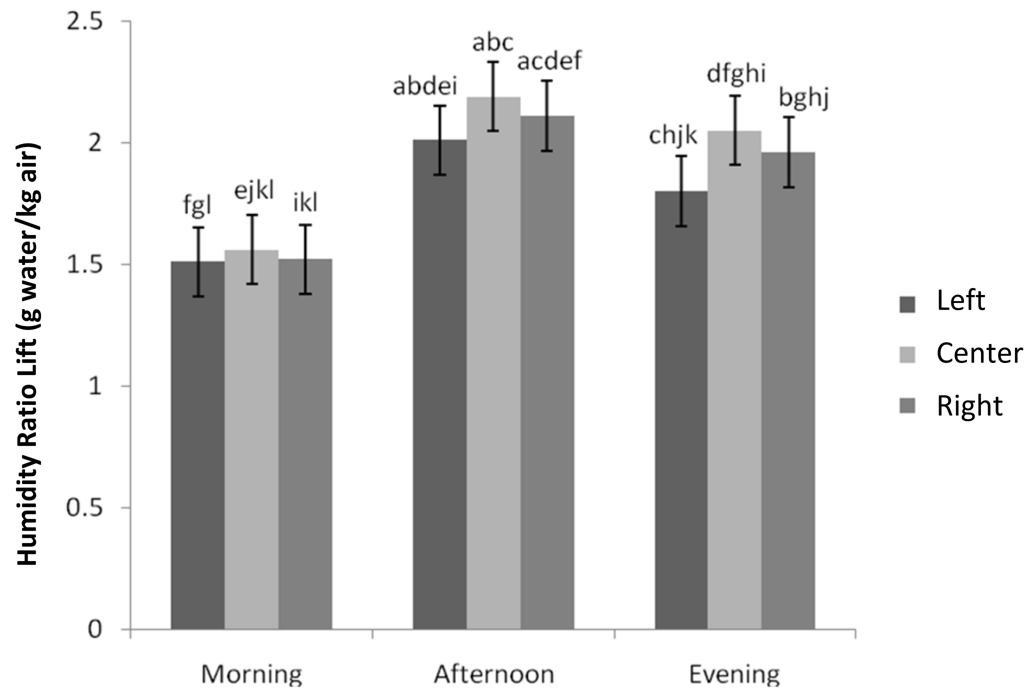


Figure 3.17. Effect of trailer plane and time of day on the humidity ratio lift for long-haul treatment ($P < 0.001$).

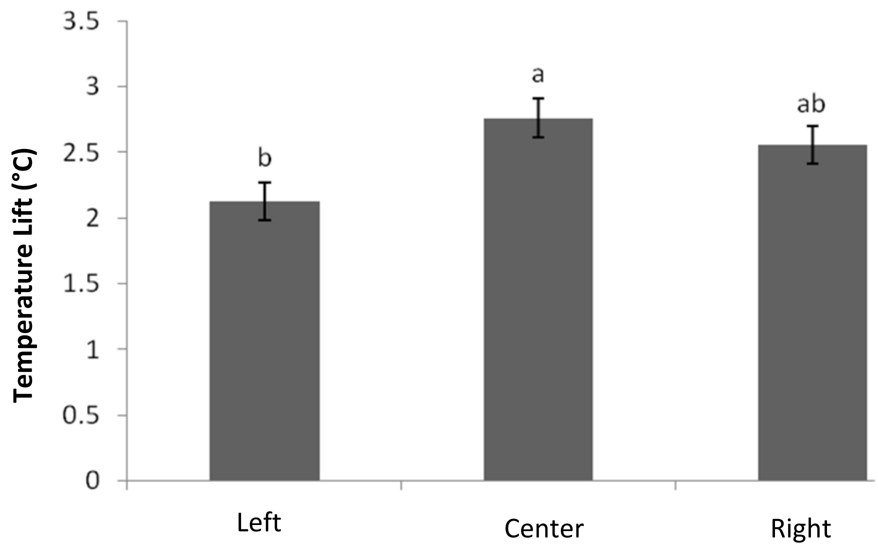


Figure 3.18. Effect of trailer plane on the temperature lift for short-haul treatment ($P < 0.05$).

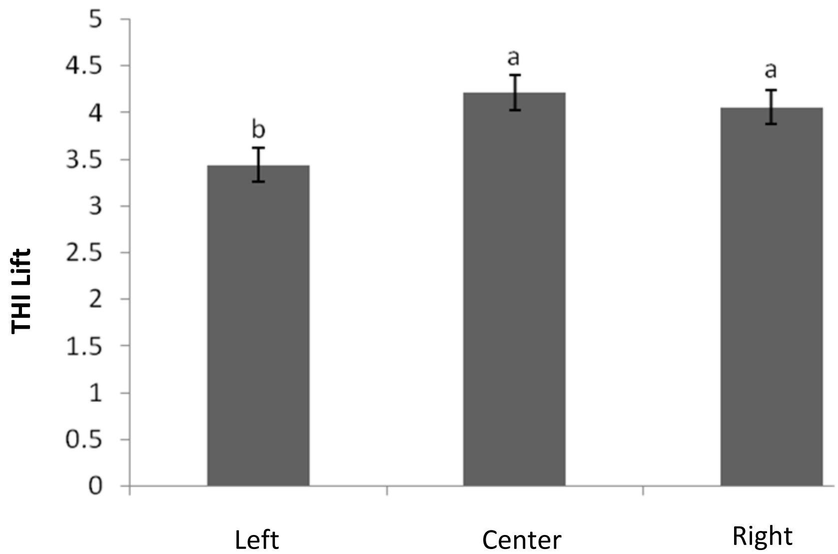


Figure 3.19. Effect of trailer plane on the THI lift for short-haul treatment ($P < 0.05$).

Predictive equations for the internal microclimate variables of inside temperature (T_{in}), THI (THI_{in}) and humidity ratio (W_{in}) using either ambient temperature (T_{amb}) or relative humidity (RH_{amb}) are presented in Table 3.11. The equations were created for both the first 15 minutes following stabilization and the last 15 minutes prior to arrival at the processing plant and were separated by treatment. Overall, temperature measured outside is a better predictor of internal conditions than is relative humidity measured outside. This is witnessed by higher R^2 values for equations generated using outside temperature compared to equations using outside relative humidity. The exception is for predicting inside humidity ratio for the last 15 minutes of the long journeys where relative humidity is actually the better predictor. The equations tend to be more predictive (higher R^2 values) for short journeys. Similarly, the equations tend to be more predictive for the last 15 minutes compared to the first 15 minutes of the journey. The only equation that was not significant was predicting internal humidity ratio using outside relative humidity for the last 15 minutes of short journeys.

The proportion of each journey classified as normal, alert, danger or emergency according to the Livestock Weather Safety Index categorizations were calculated. The THI classifications for the Livestock Weather Safety Index are as follows: normal, <74; alert, $74.1 < THI < 79$; danger, $79.1 \leq THI < 84$; emergency, ≥ 84.1. Only one short-haul journey exceeded the upper limits of normal for a very short period of time, therefore, the proportion of short journeys in each classification are not shown. The breakdown for long-haul journeys is presented in Figure 3.20. The majority of trips were conducted with THI levels in the normal range. All long-haul trips recorded conditions in the alert zone. This ranged from 2.18 to 46.27% of all readings. Even though all trips had at least three minutes in the danger zone, three trips had significant amounts of time within that category. These three trips also had the highest average trailer temperature. Journeys 3 and 5 both reached THIs in the emergency level but only represented 0.04 and 0.01% of the total trip time, respectively. Journey 4 had a slightly higher proportion of the trip falling in the alert category than the normal as well as the highest value for the danger category which was likely due to the higher absolute temperatures recorded during this journey.

Table 3.11. Linear regression equations for predicting internal trailer microclimate variables given ambient temperature or relative humidity for the first 15 minutes following the stabilization period and the last 15 minutes prior to arrival at the destination.

			R^2	*P* - value
First 15 Minutes				
	Long			
		$T_{in} = 5.89631 + 0.78293\ T_{amb}$	0.7348	<0.001
		$T_{in} = 26.3491 – 0.13367\ RH_{amb}$	0.3509	<0.001
		$THI_{in} = 47.20409 + 1.02796\ T_{amb}$	0.6967	<0.001
		$THI_{in} = 73.6066 – 0.16858\ RH_{amb}$	0.3044	<0.001
		$W_{in} = 6.78 + 0.10713\ T_{amb}$	0.0794	<0.001
		$W_{in} = 6.95 + 0.02209\ RH_{amb}$	0.0561	<0.001
	Short			
		$T_{in} = 4.49973 + 0.8615\ T_{amb}$	0.9735	<0.001
		$T_{in} = 28.44606 – 0.17804\ RH_{amb}$	0.5314	<0.001
		$THI_{in} = 43.81678 + 1.18554\ T_{amb}$	0.9646	<0.001
		$THI_{in} = 76.64867 – 0.24367\ RH_{amb}$	0.5257	<0.001
		$W_{in} = 4.93 + 0.18123\ T_{amb}$	0.4051	<0.001
		$W_{in} = 7.81 – 0.00369\ RH_{amb}$	0.0018	0.012
Last 15 Minutes				
	Long			
		$T_{in} = 6.12671 + 0.83968\ T_{amb}$	0.7906	<0.001
		$T_{in} = 36.80847 – 0.12197\ RH_{amb}$	0.3791	<0.001
		$THI_{in} = 66.19538 + 0.38993\ T_{amb}$	0.2028	<0.001
		$THI_{in} = 77.81175 + 0.0424\ RH_{amb}$	0.0543	<0.001
		$W_{in} = 24.46 - 0.45489\ T_{amb}$	0.1152	<0.001
		$W_{in} = 3.35 + 0.23533\ RH_{amb}$	0.7052	<0.001
	Short			
		$T_{in} = 3.67191 + 0.8973\ T_{amb}$	0.9776	<0.001
		$T_{in} = 27.61882 – 0.17335\ RH_{amb}$	0.3764	<0.001
		$THI_{in} = 43.61649 + 1.17427\ T_{amb}$	0.9706	<0.001
		$THI_{in} = 74.86527 – 0.22355\ RH_{amb}$	0.3628	<0.001
		$W_{in} = 3.95 + 0.21253\ T_{amb}$	0.4782	<0.001
		$W_{in} = 7.07 + 0.00305\ RH_{amb}$	0.0007	0.082

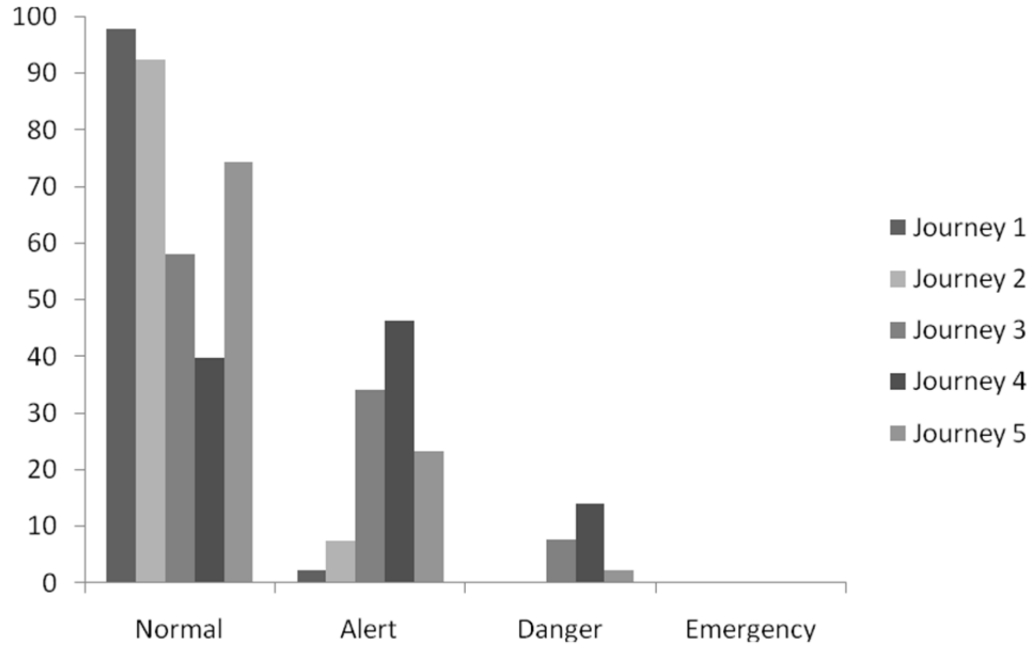


Figure 3.20. Proportion of each long-haul journey in each of the four Livestock Weather Safety Index ranges. Calculated as the number of readings over the entire journey.

3.3.2 Animal Level Microclimate

The relationship between temperatures recorded at the animal level on the ear tag, temperatures recorded at the ceiling level of the trailer and ambient temperatures recorded on the truck mirrors are presented in Figures 3.21 through 3.23. The animal-level temperature is consistently higher than trailer temperature and trailer temperature is greater than ambient temperature. This relationship holds regardless of trip length when the vehicle is in transit. Tag, trailer and ambient temperatures rise in tandem following a slight decrease at the beginning of the journey for long-hauls. Peaks in all three temperatures can be seen when the vehicle is stationary. For short-haul journeys, the temperatures remain relatively constant.

A significant compartment by time of day interaction ($P < 0.001$) was found for the variable describing the difference between temperatures recorded at the animal-level and temperatures recorded at the trailer ceiling for long-haul journeys. In the morning, the temperature at the animal-level was greater than the temperature at the ceiling-level for all compartments. In the afternoon, the animal-level temperature was less than the trailer temperature for the nose compartment only. In the evening, the nose, deck and doghouse trailer temperatures were greater than the tag temperatures. Temperature lift values were lowest in the evening for all compartments. The trailer temperature was always higher than the tag temperature for the back and belly compartments.

The difference between temperatures recorded at the tag and at the ceiling was affected by compartment only ($P < 0.001$; Figure 3.24) for short journeys. Temperatures recorded at the tag-level compared to the ceiling-level in the back compartment were significantly higher than the nose compartment. The nose had a negative lift value indicating that ceiling temperatures were greater than tag temperatures.

The compartment by time of day interaction was significant (*P* = 0.019) for the temperature lift between the tag and ambient conditions. The temperature lift decreased throughout the day and was positive for all compartments except the nose in the evening. The temperature lift tended to be the lowest in the nose followed by the back, belly, deck and then doghouse. This finding is different from the lift values for tag temperature versus trailer temperature where the back and belly tended to be the highest.

The time of day significantly affected the temperature lift between the tag and outside measurements for short-haul journeys (*P* = 0.028). Temperatures recorded at the tag were on average 4.5°C higher than temperatures recorded on the truck mirrors in the morning which was significantly higher than a difference of 2.9°C in the afternoon.

Similar to the analysis for the trailer environment, predictive equations for temperatures experienced at the animal-level were created using ambient temperature and ambient relative humidity as variables (Table 3.12). For both treatments, ambient temperature (T_{amb}) was a better predictor of animal-level temperature (T_{tag}) than ambient relative humidity (RH_{amb}). Tag temperature could be better predicted in the last 15 minutes for the long-haul compared to the first 15 minutes for both ambient temperature and relative humidity. For short journeys, ambient temperature could explain the same amount of variation in tag temperature for both the first and last 15 minutes of the trip. Relative humidity was a better predictor of tag temperature in the first 15 minutes compared to the last. In general, the R^2 values, and thus the efficacy of the predictive equations, were better for short journeys.

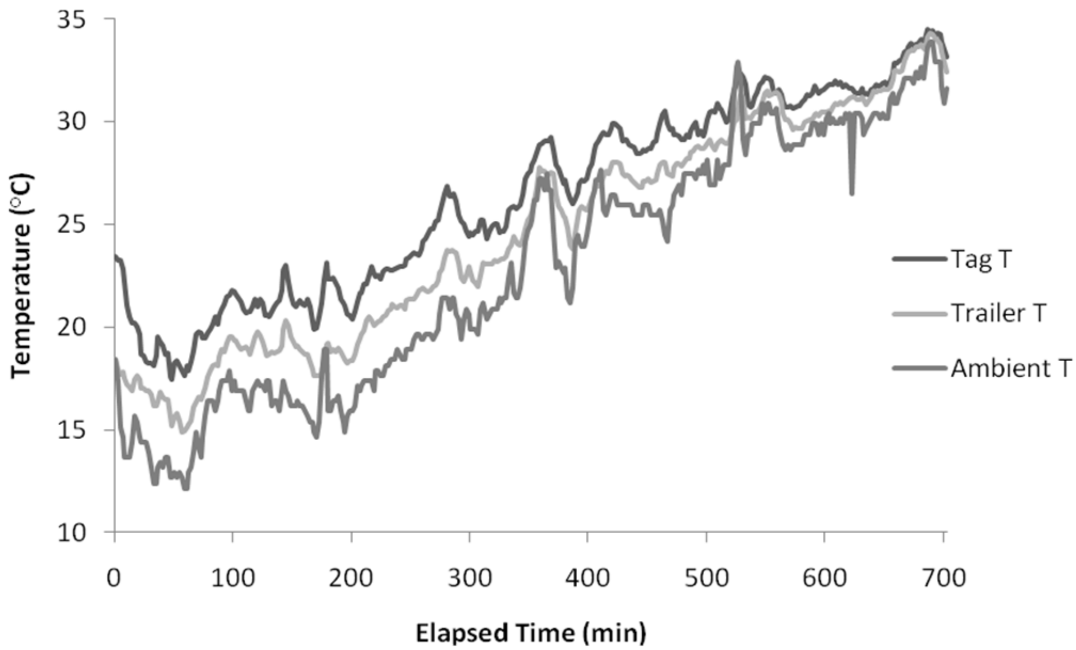


Figure 3.21. Average tag, trailer and ambient temperatures over time for long-haul Journey 2.

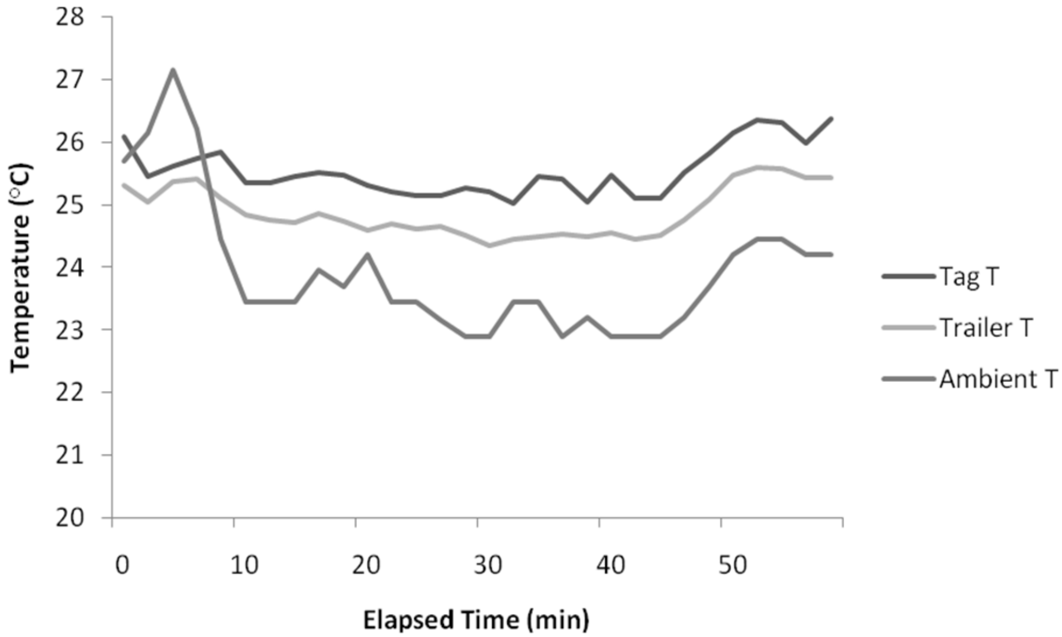


Figure 3.22. Average tag, trailer and ambient temperatures over time for short-haul Journey 3.

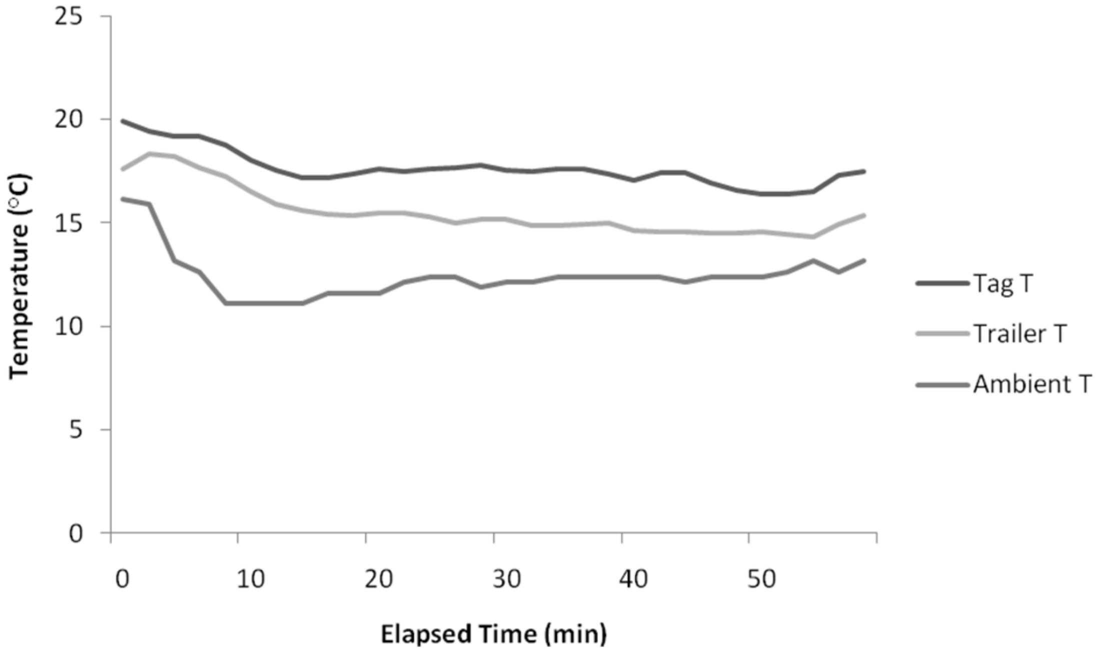


Figure 3.23. Average tag, trailer and ambient temperatures over time for short-haul Journey 5.

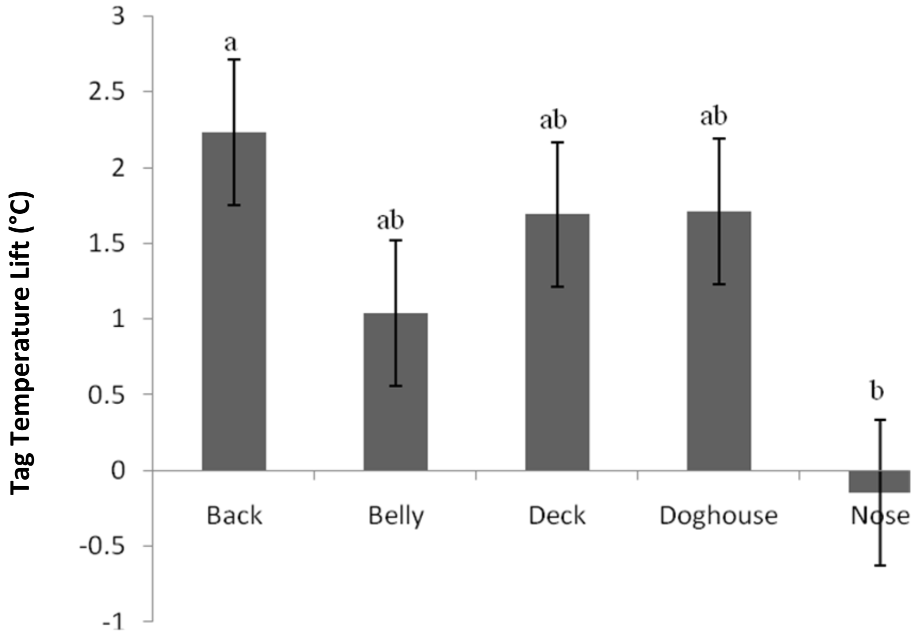


Figure 3.24. Compartment effect on tag and inside temperature lift for short treatment ($P < 0.001$).

Table 3.12. Linear regression equations for predicting animal level temperature given ambient temperature or relative humidity for the first 15 minutes following the stabilization period and the last 15 minutes prior to arrival at the destination.

			R^2	***P* - value**
First 15 Minutes				
	Long			
		$T_{tag} = 8.54324 + 0.068148\ T_{amb}$	0.5822	<0.001
		$T_{tag} = 26.23786 – 0.1141\ RH_{amb}$	0.2646	<0.001
	Short			
		$T_{tag} = 6.92029 + 0.78168\ T_{amb}$	0.8739	<0.001
		$T_{tag} = 30.08822 – 0.18346\ RH_{amb}$	0.5938	<0.001
Last 15 Minutes				
	Long			
		$T_{tag} = 6.813 + 0.81596\ T_{amb}$	0.7653	<0.001
		$T_{tag} = 37.39501 – 0.14148\ RH_{amb}$	0.3878	<0.001
	Short			
		$T_{tag} = 6.30194 + 0.8124\ T_{amb}$	0.8744	<0.001
		$T_{tag} = 28.31862 – 0.16207\ RH_{amb}$	0.3543	<0.001

3.3.3 Shrink

The percent of body weight lost differed by treatment and trailer compartment. Long-haul animals lost significantly more weight ($P < 0.001$) than short-haul animals with values of 4.5% and 1.6%, respectively (Figure 3.25). When both transport distances are considered together, compartment values differ ($P = 0.002$). The nose had the highest overall shrink at 3.5%, followed by the combined deck and doghouse compartments at 3.2%, followed by the belly at 2.7% and the back had the lowest at 2.7% (Figure 3.26). There was also a trend ($P = 0.100$) for a treatment by compartment interaction where all long-haul compartments were significantly higher than short-haul, but within the short-haul treatment there was a difference between the nose and both the belly and the back compartments (Figure 3.27).

When long and short transport distances were considered separately, there were significant linear relationships between compartment shrink and mean compartment THI (P = 0.002 for the long treatment, P = 0.008 for the short treatment; Figure 3.28). The relationship was more positive for the long treatment and explained slightly more of the variation compared to the short with R^2 values of 0.3995 and 0.3408, respectively. However, these findings must be interpreted with care as three different scales were used to collect body weights (one at the feedlot and one at each slaughter facility). These scales were not verified and thus the accuracy of the values is unknown.

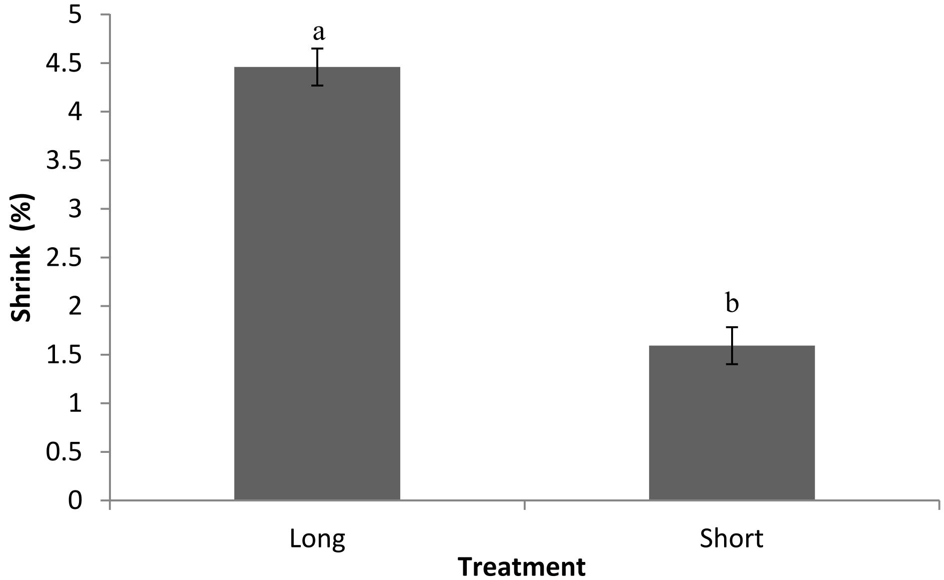


Figure 3.25. Shrink of fat heifers following long and short transport ($P < 0.001$).

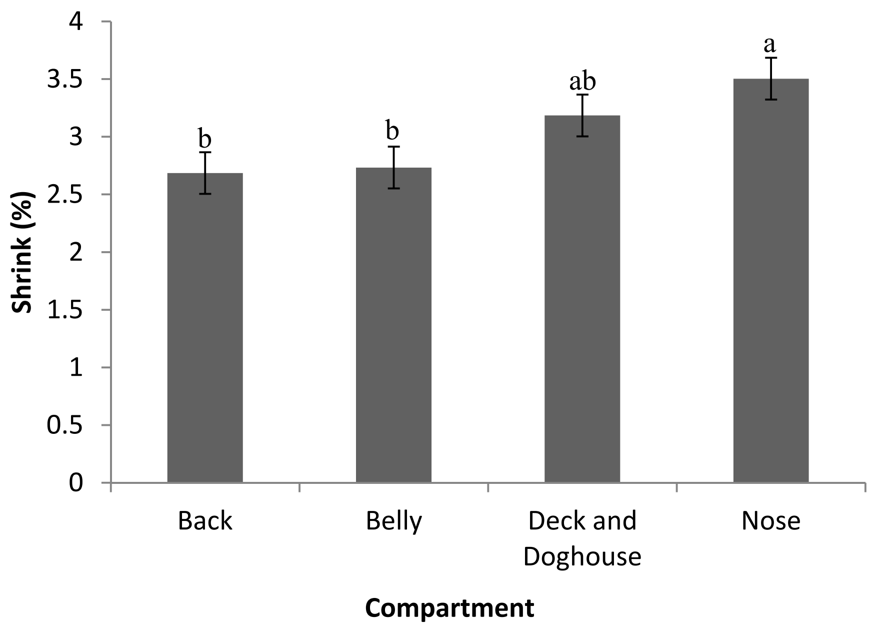


Figure 3.26. Shrink by trailer compartment for heifers transported both long and short distances (*P* = 0.002).

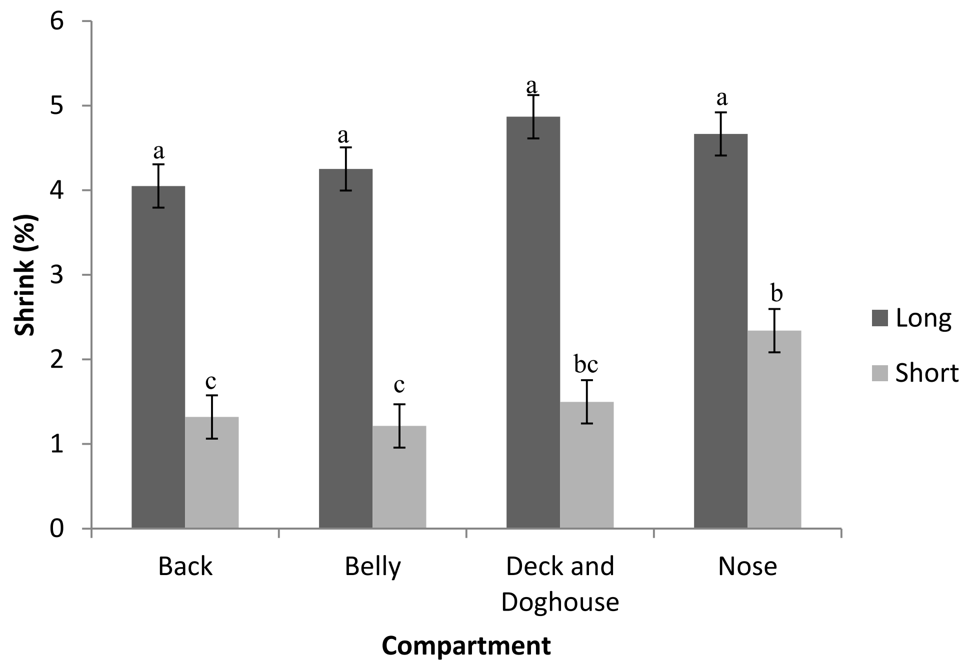


Figure 3.27. Shrink of fat heifers by transport distance and trailer compartment (*P* = 0.100).

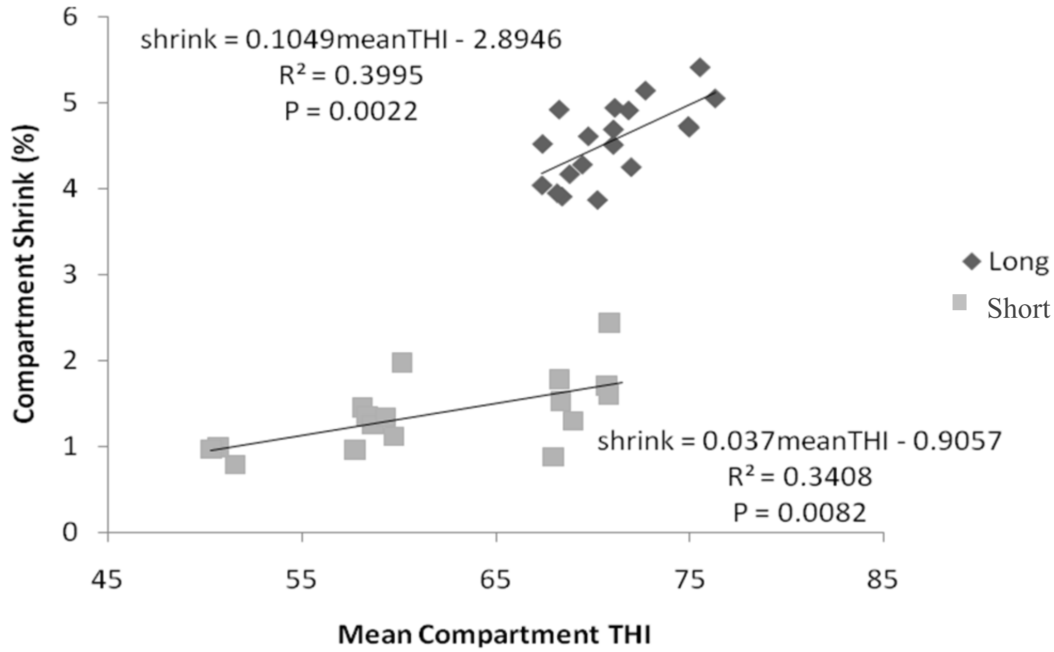


Figure 3.28. Relationship between compartment shrink and mean compartment THI by treatment.

3.3.4 Core Body Temperature

There was a significant interaction between treatment and transport event on the difference between core body temperature recorded during transport and core body temperature recorded during the baseline period (Δ CBT) (Table 3.13). For both long and short treatments, Δ CBT was highest during the loading event (first 20 minutes of transport). Δ CBT decreased during transit and at arrival (last 20 minutes of transport) for both treatments but remained significantly higher for short-haul animals compared to long-haul animals. Transit and arrival values did not differ for animals transported the long distance.

Table 3.13. Effect of treatment and transport event and their interaction on the difference between measured and baseline core body temperature.

	Long (n = 44 heifers)			**Short** (n = 55 heifers)				***P*-value**		
	Loading	Transit	Arrival	Loading	Transit	Arrival	**SEM**	Treatment (T)	Event (E)	T*E
ΔCBT	0.824^{a}	-0.008^{d}	-0.102^{d}	0.794^{a}	0.598^{b}	0.464^{c}	0.052	<0.001	<0.001	<0.001

3.4 DISCUSSION

3.4.1 Transport Environment

One of the goals of this study was to describe the trailer environment during long and short-distance transport conducted during warm ambient temperatures. Overall, the data show that the internal trailer micro-environment closely reflects the outside environment in terms of thermal conditions. A thermal gradient, however, existed between the animal level, the trailer ceiling and the outside of the vehicle with the warmest conditions experienced at the animal level. Further, a thermal gradient was also observed from the bottom compartments of the trailer to the top compartments and from the back of the trailer to the front. Moreover, within a given compartment, a gradient existed between either side of the trailer and the center. In terms of moisture, similar gradients were also observed. However, the moisture levels were greater inside compared to outside and greater on the bottom compartments relative to the top compartments. The patterns observed were similar for both long and short transport distances. The data also provide evidence that, as long as the vehicle stays in motion, there was no accumulation of heat or moisture over time, particularly for long-distance transport. Overall, these data provide insight into the patterns of air movement within naturally ventilated cattle trailers and also demonstrate the influence the animals themselves have on the trailer microclimate.

As anticipated, temperature inside the trailer closely followed outside temperatures when the vehicle was in motion. Similar findings were reported for naturally ventilated commercial vehicles hauling cattle in research conducted in Texas (Giguere, 2006), Japan (Ishiwata et al., 2008) and Sweden (Wikner et al., 2003) under similar ambient conditions. Similarly, THI and RH also closely followed ambient conditions. Fisher et al. (2004) found THI within passively ventilated lamb transport vehicles to remain parallel with ambient THI. These findings suggest that cattle transporters can extrapolate the conditions animals on board are exposed to based on the outside conditions. In fact, the regression performed in this study showed that trailer conditions can be predicted with some accuracy when using outside conditions, particularly temperature. Although a number of the regression equations presented in this research explained a statistically significant amount of variation in the data, it should be noted that much of the variability in internal conditions could not be accounted for by ambient conditions alone.

This study found that temperatures measured at the animal level were higher than temperatures measured at the trailer ceiling and the ceiling temperatures were greater than ambient temperatures measured on the truck mirrors. This supports the findings of Bryan et al. (2010) who found a gradient existed between the animal-level microclimate and the roof of a transport trailer. The results of the study by Wikner et al. (2003) also illustrated a temperature gradient between the inside and outside of a transport trailer. Like the present study, lift values were generally between 1 and 4°C and tended to decrease with time in transit.

Even though conditions inside the trailer tended to reflect ambient conditions, the trailer environment was not homogenous. Gradients existed between trailer compartments and between planes within a compartment as evidenced by temperature and moisture lift differences. This fits with the findings of White et al. (2009) who found that the environment within a trailer transporting calves varied by compartment based on weight loss outcomes and subsequent differences in performance of the calves on board.

Thermal heterogeneity within a livestock transporter has been observed in a number of studies and across different species. Brown et al. (2011) found the temperature of a pig transporter to vary from front to back and bottom to top with the lower front compartment up to

10°C warmer than ambient. Similarly, Lenkaitis et al. (2008) found the front of a trailer transporting market hogs was hotter than the back and the top deck had a higher temperature than the compartment directly beneath it. Several poultry studies have demonstrated extreme temperature gradients within transport vehicles (Burlinguette et al., 2012, Kettlewell et al., 2000, 2001; Knezacek et al., 2010), particularly during cold weather transport. Much like the findings of these studies, the present study found the front (nose) and the top (deck and doghouse) of the trailer to be the warmest. The compartment findings in this study are in agreement with Stanford et al. (2011) who also found higher THI levels in the nose and top compartments of a pot belly transport trailer. They suggested that solar radiation was likely the cause. However, the temperature differential between the animal tag and trailer ceiling found in this study suggests that the animals are generating body heat and influencing their environment. If solar radiation was the sole cause for increases in THI, it is likely that the temperature measured at the ceiling in the deck and doghouse compartments would be higher than temperatures at the animal-level. The nose and doghouse compartments had the lowest stocking density so this was likely not a contributing factor.

Although air movement within the vehicle was not measured directly, assessing the lift findings and the microclimate heterogeneity within the trailer provides some illustration of air flow patterns. The differences between trailer compartments from the back to the front and the differences from the outside walls to the centre of the trailer demonstrate the movement of air and the possible inadequacies through several compartments, the nose in particular. Other studies have suggested air moves through transporters from back to front. Poultry transporters in winter often have cold spots where air enters the trailer at the back and a thermal load at the front where air moving across the birds within the vehicle accumulates (Burlinguette et al., 2012, Kettlewell et al., 2000, Knezacek et al., 2010). Lenkaitis et al. (2008) suggest that differences observed within the pig transporter in their studies was a result of compartment dimensions but even more important was the path of ventilating air and the airflow dynamics around the trailer that contributed to the increased temperature in the front compartment. They suggested that air flowed from the back of the trailer to the front as higher levels of CO_2 were recorded in the front. This is most likely due to the fact that passively ventilated trailers rely on air entering from the outside to provide fresh airflow and to remove heat and moisture produced by the animals onboard. Ventilation is dependent upon pressure distribution. Air flows from areas where pressure is relatively high and travels to where pressure is lower (Götz, 1987). In the present study, air appears to be either entering the trailer through perforations along the side after the front compartments and flowing toward the back or entering toward the back and exiting through the perforations before reaching the front compartments.

A number of authors suggest temperature maximums for transport based on knowledge of the thermoneutral zone of cattle. Temperatures between 28 and 30°C are generally accepted as the upper critical temperature for cattle undergoing transport (Wathes et al., 1983; Randall, 1993; European Commission, 2009). The interaction between temperature and humidity is especially important when temperatures exceed 24°C (Randall, 1993). Conditions in this study exceeded the suggested maxima, and values of THI were recorded in both the Danger and Emergency categories of the LWSI. Interestingly, the proportion of long-haul journeys falling outside of the Normal LWSI category increased in journeys with mean temperatures of 24°C or above, supporting the conclusion of Randall. Overall, the conditions animals were exposed to in this study (without consideration of animal factors or acclimation) had the potential to cause heat stress.

Much like the findings of Nanni Costa et al. (2003), Fisher et al. (2004), Knowles et al. (1994), Fisher et al. (2002) and Wikner et al. (2003), changes in the microclimate were observed when the vehicle was stationary. The authors found temperature, relative humidity and THI all increase when the vehicle was stationary due to the cessation of air movement through the trailer and the resulting decrease in movement of heat and moisture out of the vehicle. Both relative humidity and humidity ratio lifts increased during stationary periods in the current study suggesting that moisture was accumulating relative to the outside (most likely as a result of the respiration and perspiration of the cattle inside). Unlike the previous research however, temperature lift and THI lift were observed to increase when the vehicle wasn't moving as heat accumulated inside the trailer. The current study often showed temperature and THI lifts to decrease during stationary periods. The explanation for this anomaly was that the ambient temperature recordings at the mirrors were being influenced by the truck itself. When the vehicle was no longer in motion, heat from the engine was not moved away from the vehicle and was able to increase the apparent ambient temperature recorded on the outside of the trailer. Therefore, relative to the outside, the inside of the trailer was cooler and the THI was lower (because of the influence temperature has on THI). When temperature inside the trailer is not looked at as lift, it is apparent that both inside temperature and THI are in fact increasing during stops. Like the above authors, it can be concluded that the most concerning conditions for heat stress and reduced welfare occur when the transport vehicle is stationary.

3.4.2 Implications for Animal Well-Being and Productivity

3.4.2.1 Shrink

The percentage of body weight loss in the present study was within the anticipated range of weight loss given the outcomes of other studies. It is well documented that levels of body weight loss range between 2 and 14% following commercial transport under various conditions (González et al., 2012b). The results of this study were similar to those reported by Mayes et al. (1979 and 1980) who assessed weight loss of slaughter animals transported different distances. Shrink in the current study was found to range between 0.79 to 3.48% for cattle transported a short distance (85 km) and between 2.58 and 5.41% for cattle transported a long distance (940 km). Similarly, the authors of the Mayes studies reported shrink to be less than 3% for animals transported 80 km and greater than 6% for animals transported 1200 km.

There are a multitude of factors which influence live weight loss including time off feed and water prior to transport (Jones et al., 1990), cattle management and handling, driver experience, the ration animals were fed and the time of day they were loaded (González et al., 2012b). The driver for this study was very experienced and practiced low-stress handling techniques. Driver experience has been shown to influence weight loss of cattle during transport (González et al., 2012b) with good practices reducing shrink. Additionally, the cattle in this study were consistently loaded in the morning for long-haul transport. These two factors could help to explain why shrink was on the lower end of anticipated levels previous studies have shown. It has been shown that cattle loaded in the morning have lower gut fill and thus lose less body weight during transport (Coffey et al., 1997). This fact could also explain why there was an increase in shrinkage between the first and subsequent short-haul loads conducted on the same day. The time of day the animals were loaded, in combination with differential environmental conditions, could explain the greater shrink observed for short-haul loads conducted later in the day.

Fill shrink itself accounts for approximately 3.2% of body weight loss (Coffey et al., 2001). If the cattle in the current study (particularly those undergoing long-haul transport) were experiencing high levels of stress we would expect the mobilization of body reserves to increase as well as the level of urination and defecation (Fell and Shutt, 1986; Phillips et al., 1982; Shorthose, 1965; Maria et al., 2004). This would lead to the shrink being considerably higher. Since the shrinkage observed was not significantly greater than the loss associated with the loss of gut fill, it is fair to assume these cattle were not experiencing undue stress.

One of the most interesting findings of the present study was the observation of differential trailer conditions by compartment. This difference was also reflected in the greater weight loss of cattle in the nose, deck and doghouse compartments. Regardless of distance, the nose showed significantly higher shrinkage than the back or belly compartments. This directly mirrors the microclimate findings and further supports the suggestion that the accumulated moisture and heat in the nose compartment created a more challenging micro-environment by decreasing the ability of the animal to dissipate heat through both latent and sensible transfer. Shrink may have increased as animals relied more on sweating to maintain a constant core temperature.

Although the overall predictive value is not high, mean compartment THI was positively related to the shrinkage recorded for a compartment of animals. This may not be a useful tool for the field (as THI is not a readily measured variable) however it helps to understand the relationship between an animal and its transport environment. Further, this relationship better illustrates the effect of transit length. Mean journey THI was similar for several long and short journeys, however shrink was always at least 1% higher for long journeys compared to a short journey conducted under similar THI conditions, suggesting that transit time was a more important factor than transit condition in determining animal response.

Overall, the low levels of shrink suggest that the transport of the heifers under conditions in this study is acceptable. The weight lost was typical for loss of rumen contents, manure and urine. The shrink findings suggest that the animals were not experiencing unacceptable levels of fatigue or stress.

3.4.2.2 Body Temperature

Our study suggests that the micro-environment inside the trailer had the potential to cause heat stress, especially for long-haul animals exposed to high temperatures (greater than 30°C) and high values of THI (greater than 74 or within the alert and danger categories). To better understand the effect on animal well-being, the knowledge of the trailer environment must be paired with animal outcome measurements, particularly body temperature. Body temperature is a good indicator of heat load in cattle and has been demonstrated to increase in heat stressed animals (Lefcourt et al., 1996, Schrama et al., 1996, Mader et al., 2006). Given this information, we would expect vaginal temperatures to increase as transport progressed, ambient temperatures increased and the thermal conditions became more taxing. This was not the case in the present study. Body temperature was seen to decrease as transit time increased for both long and short-haul cattle suggesting that heat was not being accumulated. For animals undergoing long-haul transport, body temperature was near baseline temperature in the middle and at the end of transport. Although short-haul animals had body temperatures higher than baseline at the end of and midway through the journey, these measurements were still declining indicating the animal was able to dissipate heat. These findings clearly indicate that the transport environment was not more stressful than the feedlot environment in terms of the potential for heat stress.

Although the body temperature findings did not point to heat stress, they do suggest that the animals are experiencing stress at the beginning of the journey (through elevated body temperature recordings) for both long and short transit times. This was likely due to loading, handling and general movement. This study supports the hypothesis that the loading event is the most stressful component of transport as the highest body temperatures were recorded in the loading period followed by a subsequent decline. Similar results are reported by Burdick et al. (2010) and Stockman et al. (2011) who both recorded higher body temperatures for cattle in the early stages of transport.

3.5 FUTURE RESEARCH RECOMMENDATIONS

Given some of the constraints and shortcomings of this project, several recommendations can be made for the direction of future research in this area. One major area of weakness was the difference in conditions and time of data collection for the two transport distances. Trips were conducted on different days and during different times confounding the interpretation of the results. It would be beneficial to conduct short-haul trips which covered the same periods in the day as the long-hauls. For example, information on short distance transport during the late afternoon and evening was not collected in this study but would have been useful as long distance transport was still underway at these times. This ultimately resulted in the behaviour of the internal microclimate only being assessed at two time points during the day in short-haul trips. Similarly, conducting the short and long transports within the same season, or optimally on the same day, could strengthen the conclusions we draw from the data. Further, additional trips could be conducted at different times of the year to explore seasonal variation.

Because the heifers were not slaughtered at the same packing plant on the same day between distance treatments, data on carcass characteristics were not consistent. Future experiments could be designed such that all cattle would be processed at the same facility on the same day in order to obtain useful information on carcass quality grade, yield grade, hot carcass weight and dressing percentage. These measures could further illustrate differences (or possibly similarities) of cattle transported different durations.

Further, conducting all transports on the same day could allow for the addition of other stress physiology measures which may have been confounded by the design of the current study. Blood could be collected prior to and following transport to assess parameters such as CK to identify the level of muscle exertion or fatigue, cortisol and ACTH levels to measure the stress response, or blood glucose and NEFA levels to measure energy depletion.

The analysis of the animal level microclimate could be enhanced by the use of sensors which logged relative humidity. This would have allowed for the analysis of humidity levels and moisture production where the animals are standing and could have been valuable in understanding the conditions animals are exposed to in their immediate surroundings.

An interesting finding in this study was the fact that the sensors on the truck mirrors seem to be influenced by the heat coming off the vehicle when stationary. Our study suggests that truck mirrors are not a reliable place to log ambient temperature when the vehicle is not in motion. Alternatively, loggers could be placed at several locations (such as under the trailer or on the outside wall of the trailer) to achieve a more reliable representation of ambient conditions.

Finally, to better understand air distribution and ventilation of the trailer, the distribution of temperature and humidity ratios within a compartment could be assessed. This would better illustrate gradients within the trailer (from front to back within a compartment for example) and better demonstrate where air may be entering and exiting the structure.

4 CONCLUSION

Due to the within trailer thermal and vapour gradients, several compartments (the nose in particular) experienced differential conditions and may pose a greater threat to animal well-being. Several suggestions can be made to lessen the likelihood of compromising the welfare of cattle in the deck, doghouse and nose. First, even though the nose and doghouse compartments had the lowest stocking density in the current study, loading densities within the susceptible compartments could be altered as higher densities have been shown to influence the environment (Schrama et al., 1996). The thermal conditions may actually be understated in the current study because the stocking density used was well below industry requirements. In fact, the conditions presented in this study are a best case scenario as an experienced truck driver conducted all transports following industry best practices.

Recommendations could be made to increase ventilation in the trailer to improve trailer conditions for cattle transported in warm weather, particularly for those animals in the nose compartment. Air scoops have been explored (Giguere, 2006) and may be viable for the front and top compartments that experience decreased ventilation. Additional openings in the headboard have the potential to let in exhaust from the truck and create dangerous environments inside the trailer. Similarly, additional roof vents must also avoid being too close to the truck engine exhaust. It is possible to utilize side boards to force air to move through the trailer in a more desirable pattern. This can be achieved by placing side boarding over areas of perforation holes that may be acting as air outlets. This way, air is prevented from escaping and is directed in a different pattern to reach areas of the trailer that may have previously been under-ventilated.

Decreasing the moisture inside the trailer could aid in maintaining an environment conducive to evaporative heat loss. Loading the trailer when it is dry and clean, removing manure after each haul and providing shavings to absorb moisture are all good practices but will likely not improve the environment too much because temperature drove THI in this study.

This study showed, not surprisingly, that the ambient temperature is the most predictive factor of internal trailer conditions. As a producer or transporter, this fact could aid in making transporting decisions such as when to transport cattle, what type of cattle to transport (cull cattle versus feeder cattle for instance) at what time during the day and how to manage loading density and feed and water restrictions prior to transport.

Several authors (Wathes, 1983; Randall, 1993; European Commission, 2009) suggest cattle can maintain body temperature at ambient temperatures as high as 30°C. Vaginal temperature from the current study supports this theory. In fact, the findings suggest that the cattle were able to cope with temperatures nearing 40°C even in the presence of a number of concurrent stressors. However, it is essential to keep in mind that the effect of thermal conditions on an animal is not only due to absolute values, but rather is dependent on the deviation from the threshold to which an animal is acclimated along with the duration of exposure (Scharma et al., 1996; Gaughan et al.,2008).

During warm weather transportation, a passively ventilated transport trailer can provide acceptable on-board thermal conditions for cattle, providing that the vehicle remains in motion and appropriate loading densities are respected. However, caution should be taken as mean ambient temperatures exceed 24°C due to the observed increase in the proportion of individual journeys falling in the alert and danger categories of the LWSI. A threshold of 24°C was also recommended by Randall (1993) to ensure comfort of animals during transport. Of course, the duration of exposure to a given effective temperature is important, but average temperature maxima may be useful for drafting legislation and protocols but also because of the potential for rapid induction of physiological stress. More important may be the temperature to which an animal is acclimated. In this study, temperature inside the trailer was, on average, no greater than 3°C higher than the ambient temperature. In terms of managing animal environments, achieving a temperature differential of 3°C between the animal environment and the ambient environment is acceptable, particularly when the animals have been accustomed to such conditions over time (as the heifers in this study had been). Shrink and body temperature were recorded as measures of the heifers' ability to cope with the transport event. If the animal had difficulty in coping, we would have expected to see high levels of shrink and increased body temperature, both of which were not observed. Therefore, transporting market weight heifers under conditions comparable to those of this study does not pose a significant threat to animal well-being.

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